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Fuel and Power Prospects

"THE provision of adequate fuel and power is becoming our central economic headache," said Dr. Idris Jones, Director-General of Research, National Coal Board, in his Presidential Address to the Institute of Fuel last month, in the course of which he discussed the prospective resources of fuel and power in Britain. In view of the importance of fuel to the metallurgical industries—nearly one fifth of the total costs of the iron and steel industry is represented by it—we present here a number of points raised by Dr. Jones in his survey.

In Great Britain we are faced with the problem of finding about 300,000 juveniles and young men in the next 10 to 15 years to help to produce the coal which will be required, on the basis of the predictions made in the Coal Board's Plan for Coal. Improvement in the environmental conditions of underground workers and better organisation and technical equipment of the mines are other vital needs. The right attitude to our coal reserves, more of which have been revealed by extensive boring in recent years, is not to spend too much time and energy in calculating how long they will last, but to make the best possible use of the coal we mine. If the need is great enough, ways and means will be found of getting and using vast tonnages of coal which are now considered to be unworkable and unacceptable.

The natural oil reserves of the world are being exhausted with incredible rapidity, and although new sources are constantly being discovered, this work involves increasing difficulty and cost, and eventually the time must come when oil supplies will start seriously to decline. One way out is the development of oil-from-coal (hydrogenation or synthesis) processes, but owing to high capital and running costs and costs of coal the outlook in Britain is not hopeful. Research work by the N.C.B. promises enhanced yields of tar oils as a by-product of the thermal treatment of coal for the production of smokeless domestic fuels. As a rough guess, it would appear that the oil requirements of Britain are assured for at least another 100 years.

The output of electricity in Britain has increased fourfold during the past 20 years, and this trend is likely to continue in the decades ahead. We can look forward to great developments in power generation, with two large grids linking the various Divisions of the British Electricity Authority and inter-connecting with the power system of Electricité de France, from which substantial supplies of hydro-electric power might be derived in late springtime when the snows melt in France. Generators with up to 200 MW unit capacity will be quite common, and more than three-quarters of the coal fed to power-station boilers will be pulverised fuel. The average efficiency of power generation in the United Kingdom will in a few decades be about 32%. Hydro and tidal power, equivalent to that obtained from about 6 million tons of coal, wind power equivalent perhaps to 1 million tons of coal, and nuclear power

might make a useful additional contribution to British electricity generating capacity, but increase in power demand will absorb these non-coal sources of energy, and coal will remain just as important in A.D. 2,000 as it is today. District heating and back-pressure operation of thermal stations is likely to play a major part in the heat supply of our towns and cities, and gas turbines will be increasingly employed, especially for peak-load supply. Other hopeful lines of development for small-scale use are the heat pump for heating and air conditioning of buildings and for the cooling of ventilation air in coal mines, and the fuel cell whereby it is possible to generate electricity direct from coal or its products.

There are great possibilities in the application for fuel purposes of energy derived from nuclear fission. It is now practicable to produce in the fission of the uranium isotope U235 more secondary fuel (plutonium) than is consumed of the primary fuel (U235), and this "breeder" reaction has greatly enhanced the prospects of economic development of nuclear energy. Though there are many technical and economic problems to be solved, it is possible that a reactor system may be set up that within 20 years will generate enough electricity to save 20 million tons of coal annually.

In industry generally, there will be in the future close grouping of factories to facilitate centralised heat and steam supply from high-pressure water-tube boilers, while back-pressure generation will be a common feature of future boiler and power plants, frequently providing sufficient power for the whole factory.

To eke out the resources of coking coals required for the production of metallurgical coke, scientific blending of other coals with them will be a general feature of coke-oven operation in the future, and it may be necessary to confine the use of such coals entirely to coke making. Coke for cupolas and blast furnaces may in the future be obtained from low-rank non-caking coals by suitable pretreatment followed by briquetting and carbonisation. There will be further improvement in the efficiency of utilisation of fuel in the iron and steel industry; the possibilities in this direction are exemplified by the fact that whereas 66 therms were required to produce 1 ton of steel in 1946, with the latest type of open-hearth furnace in 1953, only 37 therms were needed.

Likely technical developments in the gas industry include advance in the blending of low-rank coals for carbonisation, further improvement in the performance, efficiency and economy of continuous vertical retorts, and the use of oil gas and refinery gases. The output of gas, coke and other smokeless fuels will be increased to meet the requirements of smoke-prevention policy, and total-gasification processes will come to the fore as a means of utilising the increasing production of low-rank fines. Methane drainage from coal seams will help to augment town-gas supplies, and there is hope that the drilling programme of the Gas Council now in progress will lead to the discovery of supplies of natural gas in this country.

Bonding in Cermets

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The criterion for selecting promising cermet materials is the likely bonding behaviour between the metal and the ceramic phase. In the case of surface interaction, the surface tension of the liquid metal is of primary importance; various relationships between the surface tension of metals and other properties have been studied in order to be able to predict values for the refractory metals. For bulk interaction, the main factor involves bonding via solid solutions, and this aspect is also considered.

POTENTIALLY the most important development in ceramic technology in recent years is the conception of ceramic-metal systems, known as cermets. A great deal of field work has been done during the past decade and much valuable data and experience have been gained; but it is apparent that on the basis of *ad hoc* explanatory work, another decade might well pass without developing materials worthy of better description than "promising" with reference to a number of urgent high-temperature engineering problems. Despite serious gaps in the knowledge of phase-equilibrium diagrams, thermodynamic data, and surface tension figures available to the cermetist, there is increasing awareness of the necessity to make the fullest use of available knowledge in seeking to understand the complex problem of bonding in cermets and so aid prediction of likely systems. In this way the volume of experimental work necessary should be greatly reduced.

Cermet systems may be divided into three main types on the basis of (i) continuous, "interlocking" phases of ceramic and metal; (ii) metal dispersed in a ceramic matrix; and (iii) ceramic dispersed in a metal matrix. In all three cases the formation of an effective bond depends on one or more factors which it is convenient to consider under two main headings, "surface interaction" and "bulk interaction." The former group is centred around the phenomenon of surface tension and its effect on the interfacial tension between the ceramic and the metal, while the latter chiefly concerns the effect of forming solid solutions and definite chemical compounds. It should be noted that whereas lower surface tensions obviously improve the prospects of forming an effective bond in a given system, whether or not bulk interaction is necessary, or in fact desirable in practice (even though theoretically indicated to be beneficial), depends on the properties of the product and its stability and effect on the equilibrium of the system with regard to service conditions.

Although in some cermets the emphasis may be on electronic, nuclear, or other special properties, a number of engineering applications have in common such requirements as refractoriness, mechanical strength and resistance to thermal shock, and in the present work achievement of appreciable improvement in such properties is implicit in the term "effective bond," in addition to fundamental structural and chemical considerations as with metal alloys, the properties of the composite material for a particular application may be very much better than those of its components; there is already ample evidence from reported test figures to show that a mere compromise between the properties of

the ceramic and the metal is by no means all that can be expected. In choosing components for a cermet system, the more obvious considerations, such as a desirable combination of properties and matching of thermal expansion coefficients, must be supplemented by a study of likely bonding behaviour, if the experimental work is to be undertaken with reasonable assurance of success.

Surface Interaction

From its nature the metal generally has a greater tendency than the ceramic to spread under the conditions of sintering or hot-pressing, so that, unless the metal content is quite low, the cermet will usually tend to contain a continuous metal phase; in any case physical wetting of the ceramic by the metal is bound to be an important factor in keying the phases together.

In cermets of the oxide-metal type, for example, it is possible to distinguish three cases of wetting by surface interaction:—

(i) Macro-wetting of the ceramic by the metal.

The starting materials in this case would be either a simple mixture of the ceramic and metal powders of fairly small particle size, i.e., of the order of 1 to 10 μ , or a porous ceramic compact into which metal infiltrates in the molten state. Provided interfacial energy conditions favour wetting, this will occur at or near the melting point of the metal.

(ii) Solid wetting, or dispersion of the ceramic particles by the metal in the solid state (i.e., appreciably below its melting point), the latter being produced *in situ* in finely divided form by decomposition of a metal compound such as the hydride. The ceramic too could probably be produced in finely divided form, from the carbonate for example. Rapid interaction between two such finely dispersed phases should take place appreciably below the melting point of the metal in consequence of the high surface energies of the materials.

(iii) Wetting assisted by direct lattice fit. This possibility is considered primarily in relation to conditions intermediate between (i) and (ii), in particular, the case of a very fine ceramic powder (generally produced *in situ*) being wetted by a normal metal powder close to its melting point. The high surface energy of the finely divided ceramic is associated with distortion and disorder in the surface layers, and a proportion of these imperfections are effectively lattice "vacancies," their concentration being of a higher order than that normally encountered in coarser material. The total number of surface vacancies may then be sufficient to permit a reasonable

number of metal ions (provided their size is not prohibitive) to fit directly into the ceramic lattice. Since both anion and cation vacancies are envisaged, the "fitting" process could be aided by diffusion of oxygen atoms, a relatively small number having a considerable effect on the wetting ability of the metal. In this case the process might be thought of as a short-range dilute solid solution, with the zone of interaction limited to a surface layer of the order of 100 Å, in consequence of the steep vacancy concentration gradient in the surface layers and the small number of atoms involved.

The above possibilities, with appropriate modification to case (iii), apply also to other cermet systems, such as those with a carbide as the ceramic constituent. The example of the carbides is also useful in illustrating a general consideration which might be mentioned at this point, namely, the influence of type of chemical bond. For systems based on carbides, considerably lower interfacial tensions would be expected than for those based on oxides, in view of the fact that most of the refractory carbides concerned are appreciably metallic in character, whereas the oxides are chiefly ionic compounds.

In all three cases of wetting discussed above, the surface tension of the metal is a major factor, whether modified by the degree of fineness of the reacting powders or by the possibility of direct lattice fit. Consequently, a review of the surface tension data available has been made; the majority of these values concern the lower and medium melting-point metals, and, therefore, to predict values for the more refractory metals likely to prove useful as cermet components, the relationships between surface tension and parameters such as atomic volume, latent heat of fusion, latent heat of vaporisation, and temperature of fusion have been considered. Before dealing with the results of this study, it is of interest to review briefly some recent literature on the subject of the surface tension of liquid metals.

Atterton and Hoar¹ propose that surface tension is inversely proportional to atomic volume, but are not yet able to justify the relationship on theoretical grounds. Mukherjee² claims better correlation between surface tension and heat of fusion, with the metalloids antimony and bismuth as exceptions among the elements considered.

Referring to the proposal put forward by Atterton and Hoar¹, Smith³ notes that he came to the same tentative conclusion many years previously, based on determinations at the Royal Mint of the surface tensions of the commoner metals. He plotted the reciprocal of surface tension (γ) against atomic weight (A) and side by side with atomic volume (V), and observed the resemblance to Lothar Meyer's curve. The resemblance was even closer when $V^{\frac{1}{3}}$ was substituted for V .

Weale⁴ recalls that Schytil⁵ has shown surface tension to be related to temperature of fusion (T_f) and atomic volume (V) according to the equation

$$\gamma = K_1 T_f V^{-1} \quad (i)$$

and that this can be converted to an equation similar to that due to Wen Po⁶

$$\gamma = K_2 A v_D^2 \quad (ii)$$

where A is atomic weight and v_D the Debye frequency.

Huang and Wyllie⁷ and Skapski⁸ propose rather more elaborate methods of arriving at an estimate of surface tension, at present applicable only to monovalent metals due to limitations of free electron theory.

Skapski makes the point that the true basis for comparison of surface tensions is the molar basis. Con-

sidered in this way, liquid metal surface tensions are of the same order as those of other liquids, instead of much larger as when assessed on the specific basis, i.e., per unit of surface area. The same author also gives a table of temperature coefficients which have been used in the present work to reduce surface tensions to a suitable reference temperature, the temperature of fusion (T_f). Temperature coefficients are not given by Skapski for all the metals treated in the present work, but those included in Skapski's table (mercury excepted) are of the order of 0.10 ergs per sq. cm. per °K, so this value has been used for the remainder.

The molar surface tension (γ_M) is defined by

$$\gamma_M = A_M \gamma_s \quad (iii)$$

where γ_s is the specific surface tension and A_M , the surface area occupied by N -Avogadro's atoms, is given by

$$A_M = f N^{\frac{1}{3}} V^{\frac{1}{3}} \quad (iv)$$

In Equation (iv), V is the atomic volume, and f is a "structure factor" for the liquid, having values of 1.09 for close-packed structures and 1.12 for body-centred cubic.

The modern version of the Lothar Meyer curve is obtained by plotting atomic volume against atomic number, instead of against atomic weight, and with this slight difference the resemblance between the modified Lothar Meyer curve ($V^{\frac{1}{3}}$ v. atomic number) and a plot of the reciprocal of specific surface tension against atomic number was noted for the metallic elements. Information for the latter curve is still sketchy, but more data are now available than when this comparison was originally made by Smith³. Not quite so well defined, but still apparent, is a resemblance between the modified Lothar Meyer curve and a plot of the reciprocal of temperature of fusion against atomic number.

These similarities are inherent in the relationship developed analytically by Schytil⁵ (See Equation (i)) and this work has been taken as the basis for the present study. Six correlations have been investigated, four of these based on the work of Schytil. Ready availability of essential information has been an important consideration in the choice of all parameters.

The first plot, then, is due to Schytil

$$\gamma_s \text{ v. } \frac{T_f}{V^{\frac{1}{3}}} \quad I$$

The second is readily obtained via Equations (iii) and (iv) if the small variation in the structure factor (f) is neglected; thus we have

$$\gamma_M \text{ v. } T_f \quad II$$

Further, the entropy of fusion (ΔS_f) and the entropy of vaporisation (ΔS_v) are reasonably constant (the metalloids excepted in the former case), so a link with the latent heats of fusion and vaporisation respectively (ΔH_f and ΔH_v) is provided via the entropy quantities at the reference temperature (T_f). Thus two more simple relationships are obtained,

$$\gamma_M \text{ v. } \Delta H_f \quad III$$

and

$$\gamma_M \text{ v. } \Delta H_v \quad IV$$

Mukherjee's claim² for good correlation between specific surface tension and heat of fusion was thought worthy of fuller investigation, giving

$$\gamma_s \text{ v. } \Delta H_f \quad V$$

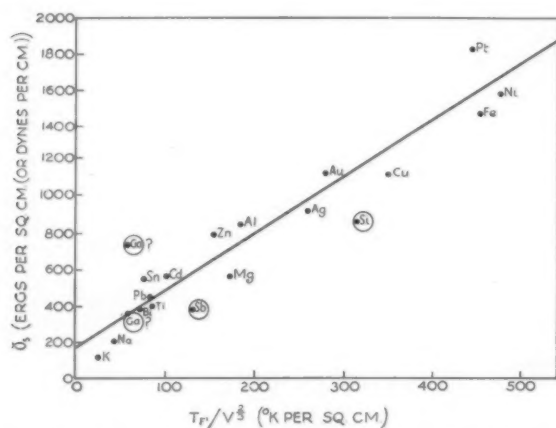
and, finally, another simple relationship

$$\gamma_s \text{ v. } T_f \quad VI$$

was included, in view of its particularly promising appearance compared with other plots, when possible

TABLE I.—EQUATIONS OF SURFACE TENSION RELATIONSHIPS.

| Relationship | Equation |
|--------------------------------|---|
| I γ_s v. $T_F/V^{1/3}$ | $\gamma_s = 167 + 3.14 T_F/V^{1/3}$ |
| II γ_M v. T_F | $\gamma_M = 1061 + 2.72 T_F \times 10^8$ |
| III γ_M v. ΔH_F | $\gamma_M = 1031 + 1141 \Delta H_F \times 10^8$ |
| IV γ_M v. ΔH_V | $\gamma_M = 782 + 48.2 \Delta H_V \times 10^8$ |
| V γ_s v. ΔH_F | $\gamma_s = -40.7 + 362 \Delta H_F$ |
| VI γ_s v. T_F | $\gamma_s = -60.5 + 0.892 T_F$ |

Fig. 1.—Relation between specific surface tension and $T_F/V^{1/3}$.

relationships were being given preliminary consideration.

Surface tension data have necessarily been drawn from a number of sources^{9, 10, 11, 12} but although this means that different experimental methods are represented, as far as possible values determined in the same atmosphere (hydrogen) have been used. Figs. 1 to 6 show the results of plotting the relationships enumerated above. As a first basis for comparison, the circled points for antimony, silicon and gallium have been excluded from the calculations of correlation coefficients and equations of lines-of-best-fit, because of the markedly metalloid nature of antimony and silicon, and the large discrepancy between the values reported for the surface tension of gallium from equally reliable sources.^{9, 10, 11} All information required for the six plots has been adjusted to the same reference temperature (T_F). In

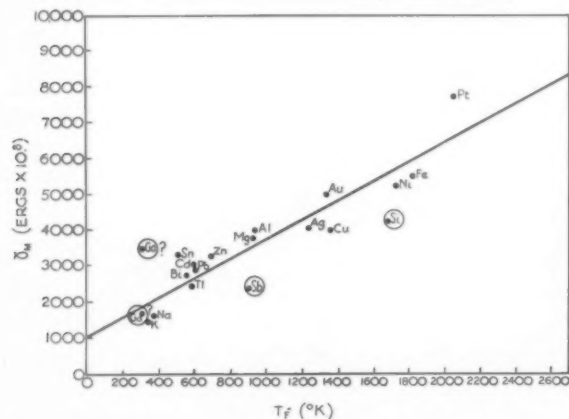


Fig. 2.—Relation between molar surface tension and temperature of fusion.

addition to references already quoted^{9, 10, 11, 12}, this information (thermodynamic data in particular) has been drawn from works by Quill¹³, Kubachewski¹⁴ and Katz and Rabinowitch¹⁵.

The equations for the six relationships are given in Table I.

The correlation coefficients are all of the order of 0.9 and above, i.e., well over the level of significance for a probability of 0.001. If the metalloids antimony and silicon were included in the calculations, the correlation coefficients for the two relationships involving ΔH_F (III and V) would be considerably reduced, since the antimony point lies well below the line in both cases, and silicon, with a ΔH_F value of 11.1 k. cal. per gm. atom, is outside the range of values represented in Figs. 3 and 5. The effect would be smaller but still appreciable for γ_s v. T_F (VI): the remaining three (I, II, and IV) would be only slightly affected by including antimony and silicon. All things considered, it would seem that these three relationships, based on Schytl's work, show most promise in the light of data available at present.

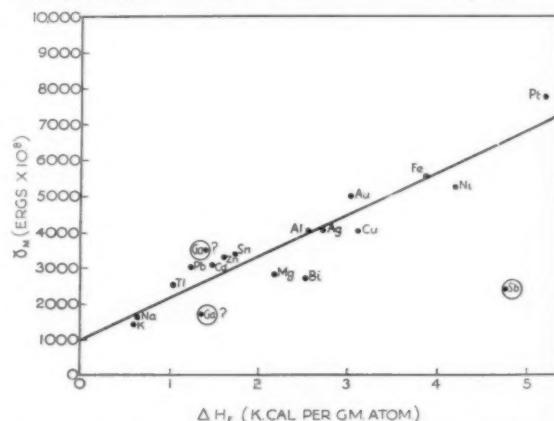


Fig. 3.—Relation between molar surface tension and heat of fusion.

As well as requiring additional surface tension figures, it would be desirable to check existing data using a standard method and atmosphere. Udin and co-workers^{16a, b, c} have given a procedure for determining the surface tension of a solid metal close to its melting point, and from the solid state value it should be possible to obtain the specific surface tension of the liquid metal, bearing in mind that the molar surface tension of the liquid is theoretically equal to that of the solid at the same temperature.

The tendency of a body to lower its free energy by decreasing its surface gives rise to a force in the surface numerically equal, in terms of unit length, to the free energy per unit area of the surface. Thus the specific surface tension, γ_s , may be expressed in dynes per cm.

or ergs per sq. cm. Similarly, surface tension may be determined either by a mechanical measurement of surface force, or by a thermodynamic measurement of surface energy. Udin and his associates chose the first approach to determine the surface tensions of copper, gold and silver.

The experimental procedure is to suspend small weights of increasing magnitude from a series of fine wires of uniform cross-section. This array is brought to a temperature at which creep is appreciable under small stress. If the applied load overbalances the contracting force of surface tension the wire extends, and by observing changes in gauge lengths the balancing applied load can be obtained from a plot of strain v . load. This point of zero strain is a measure of the surface tension. In early work by this method it was assumed that grain boundary energy in a pure metal was very

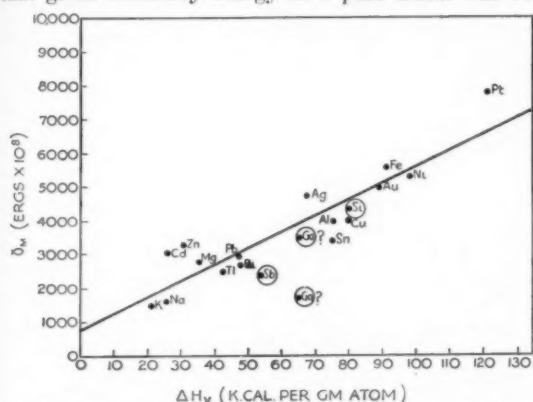


Fig. 4.—Relation between molar surface tension and heat of vaporisation.

small compared with the energy of an external surface, but subsequent experimental evidence shows that grain boundary energy is generally about one-third of the energy of an external surface. Hence a correction is necessary to the simple treatment outlined, which otherwise gives a value appropriate to a single crystal specimen. Equations for the single crystal and polycrystalline cases are developed in the papers quoted^{16 a, b, c}.

It is the "single crystal" solid value that can be used to obtain the specific surface tension of the liquid. The molar surface tension of the liquid is equal to that of the solid at the same temperature, as noted previously, but the surface area occupied by N -Avagadro's atoms in the liquid state is greater than that for the solid in proportion to the "structure factor" f (see Equation (iv)), having values of 1.09 for close-packed structures and 1.12 for body-centred cubic. Hence, the specific surface tension for the liquid may be obtained from the "single crystal" solid value on dividing by the appropriate structure factor.

TABLE II.—EXPERIMENTAL AND CALCULATED SURFACE TENSIONS OF COPPER, GOLD AND SILVER.

| Metal | Experimental γ_s (solid) (dynes per cm.) | | Temperature Coefficient (dynes per cm. per °K) | Calculated γ_s (liquid) (dynes per cm.) | Experimental γ_s (liquid) (dynes per cm.) |
|----------------|--|-------------------------|---|---|---|
| | Single Crystal | Polycrystalline Mass | | | |
| Copper | 1370 \pm 85 | 1650 \pm 100 | -0.55 | 1240 | 1126 |
| Gold | 1250 \pm 50 | 1400 \pm 65 | -0.43 | 1130 | 1124 |
| Silver | 990 \pm 75 | 1140 \pm 90 | -0.47 | 890 | 927 |

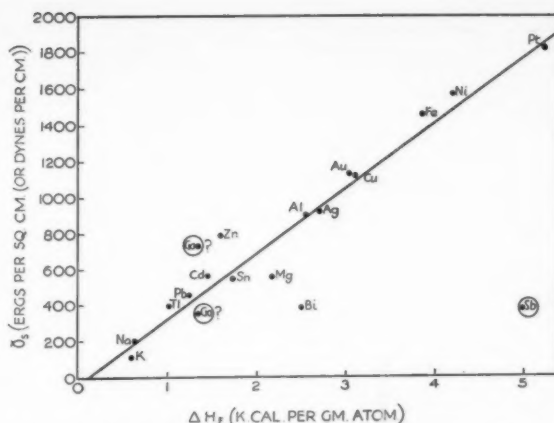


Fig. 5.—Relation between specific surface tension and heat of fusion.

In Table II, data determined by the Udin "stretched wire" method are given for solid copper, gold and silver, together with calculated and experimental liquid surface tensions for these metals.

The experimental solid surface tension data and temperature coefficients are those reported by Udin and co-workers^{16 a, b, c} and in all three cases the range of temperatures employed was within 100°K of the melting point, the average temperature being roughly 40°K below the melting point. Consequently, in calculating liquid surface tensions from these data, an approximate adjustment of -20 dynes per cm. (using the temperature coefficients in Table II) has been applied to the "single crystal" values before dividing by the factor of 1.09 for close-packed structures. Considering the range of error for the solid values, and a probably comparable range

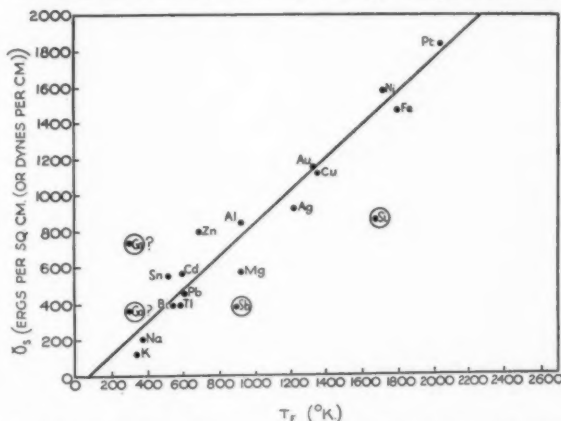


Fig. 6.—Relation between specific surface tension and temperature of fusion.

TABLE III.—CALCULATED SURFACE TENSIONS OF LIQUID METALS.

| Metal | γ_s v. $T_F/V^{\frac{1}{3}}$ I | γ_M v. T_F II | γ_M v. ΔH_F III | γ_M v. ΔH_F IV | γ_s v. ΔH_F V | γ_s v. T_F VI |
|----------|--|---------------------------|-----------------------------------|----------------------------------|---------------------------------|---------------------------|
| Be | 1800 | 1917 | 1406 | 1623 | 864 | 1330 |
| Cr.. .. | 1926 | 1900 | 1370 | 1197 | 1226 | 1880 |
| Co | 1680 | 1738 | 1540 | 1652 | 1284 | 1517 |
| Mn | 1404 | 1448 | 1385 | 1020 | 1208 | 1293 |
| Mo | 2165 | 2072 | 2020 | 1720 | 2370 | 2500 |
| Ta | 2202 | 2080 | 2010 | 2098 | 2680 | 2860 |
| Ti | 1430 | 1380 | 1330 | 1260 | 1623 | 1724 |
| U | 955 | 920 | 852 | 1037 | 1045 | 1193 |
| V | 1608 | 1580 | 1376 | 1560 | 1480 | 1697 |
| W.. .. | 2653 | 2520 | 2440 | 2300 | 3007 | 3200 |
| Zr.. .. | 1428 | 1342 | 1290 | 1180 | 1949 | 2080 |

(not reported) for the experimental liquid values, the calculated liquid surface tensions are very reasonable. Agreement between calculated and experimental values is considerably closer for gold and silver than for copper; this may be due in some measure to refinements in technique in the considerable time intervening between the "stretched wire" work on copper and that on gold and silver, and also to the use of an atmosphere of purified helium for the later work in place of vacuum. Depending on the degree of vacuum employed, vaporisation could affect the results for copper.

The above approach has advantages for the more refractory metals in particular, since their high melting points introduce formidable practical difficulties if conventional methods are used; whereas in the proposed method the temperatures employed need be little higher than the minimum at which creep is appreciable under a small stress, and the metal does not have to be handled in the molten state.

Returning to the surface tension relationships studied by the present authors, calculated values of γ_s (liquid) at the melting point are given in Table III for a typical list of metals with melting points above 1,500°K which are potentially useful as cermet components for high-temperature engineering applications. Uranium has been included in the table in view of its special importance in the nuclear power field.

The surface tensions were calculated from the equations listed in Table I, corresponding to the straight lines of Figs. 1 to 6 (i.e., neglecting antimony, silicon and gallium). It is of interest to note the reasonable overall agreement of values predicted by the relationships based on Schytil's work (I to IV), and, in particular the quite close agreement (chromium excepted) for relationships I, II and IV, i.e., the three least affected by including the metalloids antimony and silicon. The general conclusion from the calculated and experimental figures for liquid refractory metals is that the surface tensions are too high to favour simple wetting.

In conjunction with the surface tension of the liquid metal and the contact angle between the metal and the solid ceramic, the surface tension of the ceramic is important in determining the interfacial tension. There is no information on the surface tensions of the carbides, and very little available for the oxides. Norton and Kingery¹⁷ have calculated the surface tensions of alumina and zirconia at 1,850°C. from experimental measurements of "dihedral" angles, and obtained values of 905 and 590 dynes per cm. respectively. Investigations on the surface chemistry of oxides are largely those due to Fricke and his collaborators, who carried out a large number of experiments on the heats

of solution of oxide and hydroxide powders. By combining these with surface area measurements, they were able to obtain values of the surface tension of the solid oxide. Thus for CdO^{18} the value they obtained was 500 dynes per cm. The few values available, therefore, indicate that the surface tensions of the oxides are roughly a little less than half those of the refractory metals likely to be of interest.

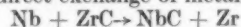
Bulk Interaction

In conjunction with the interfacial tension considerations affecting material at or near surfaces of interaction of cermet constituents, the formation of solid solutions and chemical compounds may be desirable, or even essential, for effective bonding. The nature and extent of the interaction product (or products) may largely determine the usefulness of a cermet for a specific application, so possible bulk interactions in various forming conditions must be considered together with the approach to equilibrium to be expected in these conditions. It is not essential to achieve equilibrium, provided the rate of interaction under service conditions is negligible, in order that no appreciable change in structure or properties should occur.

The present discussion is limited to the bonding of oxide and carbide cermets, but similar considerations apply to other promising systems, such as those based on the nitrides, silicides and sulphides.

(i) *Solid Solutions.* Usually, solid solution bonding involves the addition, or formation *in situ*, of a small amount of the appropriate ceramic form of the metal constituent; examples of the type of phase involved are provided by the systems $\text{Al}_2\text{O}_3\text{-Cr}_2\text{O}_3$ and NiO-MgO for oxides, and TaC-TiC and NbC-ZrC for carbides. These systems form continuous series of solid solutions, but there are also many suitable systems in which solid solution occurs over a limited range only.

Considerable attention has been given to $\text{Al}_2\text{O}_3\text{-Cr}$ cermets, for example by Blackburn, Shevlin and Lowers¹⁹, leading to the opinion that a small amount of Cr_2O_3 in solution in Al_2O_3 is necessary for the formation of an effective bond in these cermets. But, whereas direct addition of Cr_2O_3 , or some technique such as controlled reduction of Cr_2O_3 (or oxidation of Cr) *in situ*, is required to achieve the desired result in a reasonable reaction time, in the case of carbide-metal combinations, such as the ZrC-Nb cermet studied by Lidman and Hamjian²⁰, faster reaction rates may make it feasible to form the required amount of the carbide of the metal constituent by direct exchange of metal atoms, thus,



with subsequent solution of NbC in the remaining ZrC.

The displaced zirconium tends to collect at grain junctions and in voids in the compact.

The foregoing cases involve bonding via a solid solution of ceramic phases, but although examples of direct solution of metal in ceramic or vice versa are fewer, it is quite feasible to achieve an effective bond in this way. Cubicciotti²¹ has found that ZrO_2 can take up to 15 atomic per cent. of zirconium into solid solution, and so it is reasonable to expect that a cermet based on ZrO_2 can be effectively bonded if zirconium be added to the chosen metal in a suitably alloyed form.

The well-established "bonded carbides" provide examples of solution of ceramic constituents in metals, notably WC^{22} and TiC^{23} in cobalt. Forming temperatures are usually such that solid solution occurs in the first instance, with consequent lowering of the melting point of cobalt and formation of a liquid phase which takes up more carbide. Precipitation of carbide on cooling forms a continuous network in conjunction with undissolved carbide, the interstices of this network being filled with cobalt retaining some carbide in solid solution; this precipitation has an important bearing on the achievement of high mechanical strengths in bonded carbides. Kieffer²² has put forward a likely explanation for the WC case based on the "healing" effect of the precipitated carbide, filling up structural imperfections which might otherwise act as local stress-raisers, and so reduce the strength of the compact as a whole. For example, the room-temperature transverse bend strength of WC bonded with 11 per cent. cobalt is quoted as 255,000–280,000 lb. per sq. in.²², i.e., about four times the figure for sintered pure WC, whereas the bend strengths variously reported for Al_2O_3 -Cr cermets with comparable or larger amounts of metal are barely twice the figure for sintered pure Al_2O_3 , viz., 24,600–35,800 lb. per sq. in.²⁴. It is interesting to speculate whether precipitation from solid solutions or liquid phases might be sought in oxide-metal systems to produce the healing effect postulated for the bonded carbides, thereby improving the mechanical properties.

(ii) *Compounds*. The classic examples of compound formation in oxide systems are the spinels, having the generalised formula $RO.R'_2O_3$ where R could, for example, stand for Ni, Mg, Fe^{++} or Co, and R' for Al, Cr or Fe^{+++} . The German firm of Siemens²⁵ was probably the first to consider the Al_2O_3 -Fe cermets, and a great deal of work has been done on this system without achieving the combination of properties required for the high-temperature engineering applications in view. However, some other likely combinations involving a spinel bond have not been so fully investigated and may yet yield a satisfactory cermet.

For carbide cermets, instances of definite compound formation as an adjunct to bonding are not so readily found. The example of Co-bonded WC might be quoted again, in that an intermediate η -phase is formed consisting of double carbides with the generalised formula $Co_2W_2C_2$ (e.g., $Co_2W_2C_2$). However, although this phase plays an intermediate role in forming an effective bond, its brittleness renders it undesirable, and by careful control of forming conditions it can be excluded from the final product.

Interfacial Tension Conditions

The probable effect of some of the bonding factors discussed above can be quantitatively assessed with the aid of simple interfacial tension calculations.

As a convenient starting point, consider a sessile drop of liquid metal on a smooth ceramic surface in a neutral atmosphere. The forces acting at the interface are related according to the equation.

$$\gamma_i = \gamma_{sc} - \gamma_{LM} \cos \theta \quad (vi)$$

where γ_i is the interfacial tension, γ_{sc} the surface tension of the solid ceramic, γ_{LM} the surface tension of the liquid metal, and θ the internal angle of contact at the interface. θ ranges from 0° for complete wetting to 180° when there is no tendency at all for the metal to spread.

As pointed out previously, one would expect, from comparison of the nature of the lattice binding forces of the components, that interfacial tensions between oxides and liquid metals would, in general, be higher and, therefore, less favourable to wetting than for carbide-metal systems. Norton and Kingery²⁶ give contact angles for nickel on Be_2C , graphite and diamond (for example, 90° , 68° , and 68° respectively, in hydrogen) which lend support to this opinion, but it should be noted that there was some evidence of reaction at the interface on all three ceramics in the atmospheres employed (vacuum, hydrogen and helium). In any case surface tension figures are not available for the carbide ceramics, so the present treatment is restricted to oxide-metal systems. The factors noted as favouring bonding in oxide cermets would be expected to exert a no less favourable influence in the case of carbide cermets.

Some idea of the values of interfacial tensions to be expected may be obtained by using equation (vi) in conjunction with data reported for the system Al_2O_3 -Ni in helium at $1,850^\circ C$.¹⁷:-

$$\gamma_{LM} = \gamma_{Ni} = 1,480 \text{ dynes per cm.}$$

$$\gamma_{sc} = \gamma_{Al_2O_3} = 900 \text{ dynes per cm.}$$

and

$$\theta = 130^\circ$$

Hence $\gamma_{Al_2O_3-Ni}$ is calculated as 1,850 dynes per cm.

For wetting to occur in the Al_2O_3 -Ni system, θ must equal 0 , i.e., $\cos \theta$ equals 1 . This limiting condition gives

$$\gamma_{Al_2O_3-Ni} = 900 - 1,480$$

$$= -580 \text{ dynes per cm.}$$

The interfacial "tension" for wetting must, therefore, be negative, and this would appear to be general in the case of liquid metals and solid oxides, since, as shown previously, γ_{LM} for the refractory metals tends to be roughly twice as great as the few values of γ_{sc} available for oxides. The total decrease in interfacial tension which must take place if wetting is to be achieved in the Al_2O_3 -Ni case is 2,430 dynes per cm. from the above figures.

For wetting to occur, therefore, between liquid metals and solid oxides, chemical interaction or formation of solid solutions appears necessary to reduce the interfacial tension by values of the order of 2,500 dynes per cm. As a simple example of the solid solution case, the system Al_2O_3 -Cr may be considered; it is generally agreed that the formation of a solid solution of a few per cent. by weight of Cr_2O_3 in Al_2O_3 is an essential step in forming an effective bond in this system. The free energy change on formation of the solid solution is thus important, and that this is of the right order for the required decrease in interfacial tension may be shown by calculations based on two assumptions, (a) that the solid solution is an ideal one, and (b) that the free energy change takes place in the surface layers.

For an ideal solution it can be shown that the free energy change

$$\Delta G = RT [x \ln x + (1-x) \ln (1-x)]$$

where x is the mole fraction of solute. In the case of Al_2O_3 -Cr cermets, investigations to date indicate that the amount of Cr_2O_3 in solid solution in the Al_2O_3 should be of the order of 4 per cent. by weight; the mole fraction of the solute is thus 0.027 and the free energy of solution at 1,620°C. is calculated as 1,300 calories per mole, or in other words the formation of the 4 per cent. solid solution results in a decrease in the free energy of the system by this value. This free energy change may be related to a decrease in interfacial tension by assuming that the solution is initially confined to the surface layers of the Al_2O_3 , say to a depth of 100Å, and calculating the area corresponding to unit molar volume.

We then have

$$A \times 100 \times 10^{-8} = \frac{\text{Molar Volume}}{\text{Mol. Wt. of Solid Solution}} \\ = \frac{\rho_{\text{Solid Solution}}}{\rho_{\text{Solid Solution}}}$$

$$\text{Now } \rho_{\text{Solid Solution}} \div \rho_{\text{Al}_2\text{O}_3} = 4$$

$$\therefore A \times 10^{-6} = \frac{104}{4}$$

$$\text{or } A = 26 \times 10^6 \text{ sq. cm.}$$

Also, the free energy change = $1,300 \times 4.18 \times 10^7$ ergs, and hence the decrease in interfacial tension is $\frac{1,300 \times 4.18 \times 10^7}{26 \times 10^7} = 2,100$ ergs per sq. cm. (or dynes per cm.)

It appears, then, that the decrease in interfacial tension associated with the formation of quite dilute solid solutions is of the right order to promote wetting. The case in point corresponds to a concentration of 1 chromium atom per 35 aluminium atoms; for the "lattice fit" possibility discussed earlier with particular reference to the case involving a very fine ceramic powder, a concentration of the order of 1 chromium atom per 1,000 aluminium atoms was envisaged, corresponding to 0.1 mole per cent. Cr_2O_3 and a decrease of interfacial tension of only 70 dynes per cm. Hence, direct "lattice fit" (which on the present basis has been considered as an extreme case of a dilute solid solution) does not appear promising as a major factor in achieving wetting and bonding, although, as shown below, the high surface energy of the ceramic powder, in consequence of its fineness as produced *in situ*, is *per se* a major factor.

The main assumption in the above work is that reactions at the surfaces of particles do not differ from those occurring in bulk, i.e., the surface layers do not differ in their behaviour from the bulk of the oxide particle, and so the surface energy of the particle is a function only of the surface tension and the radius. However, the increasing popularity of hot-pressing techniques favours the preparation of the oxide in finely divided form *in situ* by decomposition of compounds such as carbonates or oxalates; for example, the particle size of MgO prepared by decomposition of MgCO_3 at 700–800°C. is 0.02μ. Under these conditions, the surface energy of the oxide particles is likely to be much higher than that given by the normal surface tension (relating to particles greater than 1μ), due to the fact that in the former case lattice irregularities are likely to exert a dominant influence. The data obtained by Fricke and co-workers²⁷ on pyrophoric iron is relevant in this connection. They found that by reducing

amorphous Fe_2O_3 with hydrogen, pyrophoric iron was obtained at 350°C. but not at 640°C. The heats of solution of the two preparations in sulphuric acid were determined, and the heat content of the pyrophoric material was found to be 1,400 calories per gm. atom higher than for non-pyrophoric iron. The particle sizes for the two preparations were 240 and 315Å for the pyrophoric and non-pyrophoric varieties respectively, and hence, the heat quality corresponding to the difference in surface area (calculated as 200 calories per gm. atom) is insufficient to account for the higher heat content or excess surface energy of the pyrophoric material. X-ray measurements showed a pronounced decrease in the intensity of the lines with higher diffraction angles, and it was calculated that in the pyrophoric iron there was an average deviation of the iron atom from the normal position of 0.06Å. This distortion was considered responsible for the higher surface energy of the pyrophoric material. It will be noted that this higher surface energy (1,400 calories per gm. atom more than for non-pyrophoric iron) is of the same order as that calculated for formation of the 4 per cent. solid solution in the Al_2O_3 -Cr case, and on the same basis would correspond to an increase in the surface energy of the solid (the ceramic in the general case) of 3,000 ergs per sq. cm. Further, from Equation (vi) it is apparent that an increase in γ_{sc} has the same effect as a decrease in γ , i.e., $\cos \theta$ is increased, and so wetting is favoured.

Summarising the above considerations, it has been shown quantitatively that it is feasible to achieve wetting in metal-ceramic systems involving the refractory metals with high surface tensions; the approaches employed in the examples treated are (a) decreasing the interfacial tension by formation of solid solutions, and (b) increasing the surface energy and effective surface tension of the oxide by formation of very small particles *in situ*. The effect of (a) could also be achieved by formation of chemical compounds.

Conclusions

- (1) To aid selection of promising cermet systems, full consideration of the complex problem of bonding is necessary. The chief factors involved can be dealt with conveniently under two main headings, "surface interaction" and "bulk interaction."
- (2) Three cases of wetting by surface interaction can be distinguished:—
 - (i) Macro-wetting of the ceramic by the metal, depending largely on the surface tension of the molten metal.
 - (ii) Solid wetting, or dispersion of the ceramic by the metal in the solid state (i.e., appreciably below its melting point), involving production *in situ* of finely divided constituents with high surface energies.
 - (iii) Wetting assisted by direct lattice fit, both anion and cation vacant sites being involved. This process may be thought of alternatively as short-range dilute solid solution.
- (3) In all three cases of wetting by surface interaction, the surface tension of the metal is a major factor. A review of surface tension data for liquid metals shows that this information is sketchy, and, in particular, there are very few values available for the more refractory metals which *a priori* seem most likely to prove useful as cermet components. To predict surface tension values for these metals, the relationships between

surface tension and a number of simple parameters have been studied on the basis of the limited information available, and three relationships based on the work of Schytil correlate particularly well.

(4) The general conclusion from calculated and experimental values is that surface tensions of the liquid refractory metals considered, mostly in the range 1,300 to 2,500 dynes per cm., are too high to favour simple wetting. A value of the order of 1,000 dynes per cm. is indicated for liquid uranium. To check predicted values, a practical method due to Udin and co-workers for determining surface tensions of solid metals (thus avoiding the experimental difficulties of dealing with molten refractory metals) appears very promising, in conjunction with a simple method of calculating surface tensions for liquid metals from solid state values.

(5) Few surface tension figures are available for ceramics, but values for solid oxides in the range 500 to 1,000 dynes per cm. indicate that their surface tensions are somewhat less than half those of the refractory metals likely to be of interest.

(6) Under the heading of bulk interaction in cermet the chief factors are solid solution and formation of chemical compounds. Solid solution bonding usually involves a small amount of the appropriate ceramic form of the metal constituent, but direct solution of metal in ceramic or vice versa is feasible. Spinel and double carbides are examples of compound formation in bonding. The cases of bulk interaction discussed are limited to oxide and carbide cermets, but similar considerations apply to other promising systems, such as those based on nitrides, silicides and sulphides.

(7) Numerical examples illustrate the influence on the formation of an effective bond of some of the factors discussed, and show that, by inducing conditions favourable for wetting, it is feasible to promote such a

bond in metal-ceramic systems involving refractory metals with high surface tensions. Only oxide-metal systems are considered in this quantitative treatment, chiefly because of limitations of available data, but the favourable effects noted should, in general, be no less apparent for other systems. In particular, solid solution and formation of very small ceramic particles *in situ* are shown to have markedly favourable effects on interfacial tension conditions; direct lattice fit, on the other hand, makes a comparatively small contribution, and is unlikely alone to overcome the unfavourable effect of the high surface tensions of the refractory metals.

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Institute of Metals

Lectures on Lattice Defects and Brittle Fracture

A GENERAL Meeting of the Institute of Metals will be held at 4, Grosvenor Gardens, London, S.W.1., on Thursday, May 27th, at 5.30 p.m., when a lecture entitled "Lattice Defects and Energy Stored in Deformed Metals" will be given by Dr. W. Boas (Head of the Division of Tribophysics, Commonwealth Scientific and Industrial Research Organisation, Melbourne).

At another General Meeting to be held on Wednesday, June 30th, at 5.0 p.m., also at 4, Grosvenor Gardens, there will be a lecture on "The Brittle Fracture of Metals: Some New Developments," given by Professor E. Orowan, F.R.S. (Department of Mechanical Engineering, Massachusetts Institute of Technology).

The meetings will be open to visitors, without ticket. Both lectures are being given under the auspices of the Metal Physics Committee of the Institute, and are the first in a series by distinguished scientists from overseas that the Committee hopes to arrange from time to time.

Non-Destructive Testing Conference

THE Non-Destructive Testing Group of The Institute of Physics and the Midland Branch of the Institute are jointly responsible for a Summer Meeting on Non-Destructive Testing, to be held at Chancellor's Hall, University of Birmingham, from 7th-10th July, 1954.

Sessions will be devoted to the following subjects:

(1) Isotope Techniques; (2) Image Intensifiers; (3) Diffraction Mottling; (4) Theory and Application of Electrical and Magnetic Methods of Non-Destructive Testing; (5) Propagation of Elastic Waves in Solids; and (6) Selected Topics in Ultrasonic Testing. In addition, two hours of the first day are to be given over to a Forum in which a Panel of Experts will deal with questions concerning the scope and limitations of non-destructive testing. The Meeting will be open to Members and non-Members of the Group, subject to the limit of the lecture-room capacity (about 300 persons). Enrolment forms may be obtained from the Deputy Secretary, The Institute of Physics, 4, Belgrave Square, London, S.W.1, to whom they should be returned not later than May 31st, 1954.

A Pair of Helping Hands

THE strength of James Booth's M.G.7 aluminium alloy was proved recently when two clock hands, made of the alloy and little more than two feet long, averted a tragedy by supporting the weight of a man for more than five minutes. The incident occurred in Manchester, when a man who was repairing the clock of St. Mary's Hospital, 40 ft. above ground, was caught by a gust of wind and lost his balance. Fortunately, as the time shown was 5.35, both clock hands were close together and he was able to grab them and hold on until rescued.

Developments in Spot Welding

New Machine Increases Scope of Process

A REMARKABLE increase in the scope of resistance welding has followed the introduction of the G.E.C. 4 kVA. electronically controlled spot welder, which enables many non-ferrous metals not previously considered suitable, to be spot welded. Typical examples of the welders' performance are given by Standard Telephones and Cables, Ltd., who have installed several at their works in New Southgate. One is installed in the laboratory and used for developing new applications; others are used in full scale production where, with suitably designed jigs, welds which would normally have been considered difficult or impossible are achieved at high rates.

Thin, dissimilar metals representing opposite near-extremes in electrical conductivity are successfully welded in the assembly of a relay spring. The contact is of cadmium silver 0.025 in. thick and is spot welded to a nickel silver spring only 0.010 in. thick. The contact has a diameter of 0.125 in. and the weld is completed without marking the contact surface.

In the assembly of a sprung plug body (Fig. 1) the difficulty of welding brass is aggravated by the need to join to it two nickel silver springs, each 0.018 in. thick, by a common weld. The 4 kVA. spot welder enables the

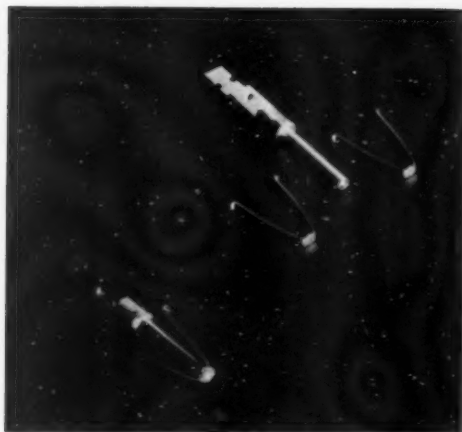


Fig. 1.—A sprung plug body in the assembly of which brass is welded to two nickel-silver springs each 0.018 in. thick, by a common weld.

two spring thicknesses to be welded simultaneously against a projection at the end of the 0.108 in. diameter body. Another good example of the machine's ability to weld dissimilar metals is the assembly of a stud contact. The brass stud is nickel plated and to it is welded a $\frac{1}{8}$ in. diameter 0.025 in. thick platinum contact.

A feature of the welder is the accuracy with which the required welding current and pressure can be determined and set up. This permits short welding times so that the heat is strictly localised round a weld. Thus, in the assembly of a coaxial socket, where two pieces of silver-plated beryllium copper each 0.015 in. thick are joined together, the weld is accomplished without annealing the surrounding metal. Localising the heat is also necessary when welding tinned nickel wire and strips to the tinned Kovar terminals of a miniature relay (Fig. 2),

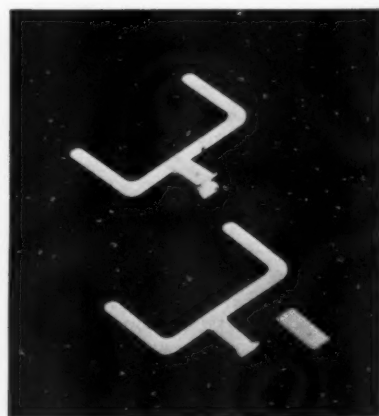
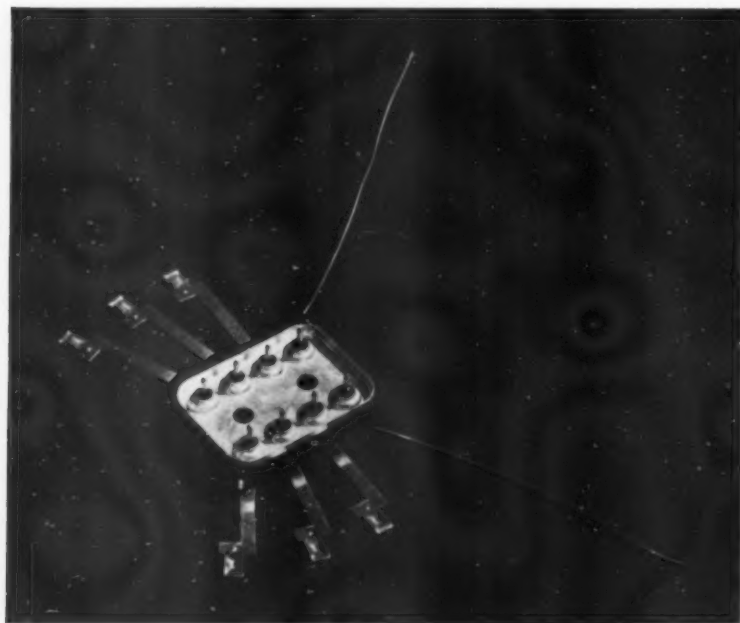


Fig. 3.—A terminal in which a total thickness of 0.040 in. of silver-plated nickel silver is welded.

Fig. 2.—Tinned nickel wire and strips welded to the tinned Kovar terminals of a miniature relay.



Fig. 4.—An operator at the New Southgate works of Standard Telephones and Cables, Ltd., using the G.E.C. 4 kVA. electronically controlled spot welder to weld a nickel-silver residual plate to an iron relay core.



Fig. 5.—Close-up of the new spot welder, showing the operating facilities of the welder and the ample working space available.

because the welds are close to a glass-to-metal seal and thermal shock must be avoided. The wires are 0.018 in. diameter, the strips 0.060 in. thick, and the terminals have a diameter of 0.040 in. The welds are effected with a minimum displacement of the plating.

The combination of short weld times with precise current and pressure requirements is most important in prolonging the life of electrodes. Absolute cleanliness is essential when thin sheets of metal are to be joined without distortion, but if the electrodes of the welder need constant cleaning, dust may accumulate on parts to be welded. With the new spot welder, constant cleaning of the electrodes is unnecessary and a deaf aid diaphragm made from Permalloy B material, and having a 0.020 in. thick slug, is satisfactorily welded to a 0.005 in. thick diaphragm without distortion and without marking the selected face. The assembly of a terminal (Fig. 3) involves the welding of a total thickness of 0.040 in. of silver-plated nickel silver. This is done with a minimum displacement of the plating. The individual thicknesses are 0.010 in. and 0.030 in.

The welder was originally designed by the G.E.C. Research Laboratories for their own use, to weld very thin wires and sheets. Its exceptional performance is largely due to the care with which the precise conditions so essential for the successful welding of many non-ferrous metals can be set up and recorded.

Introducing as it does a new conception of the art of spot welding, the welder is virtually a new type of machine. Special features are incorporated to ensure accurate repetition work. The fully variable controls for current and pressure have graduated scales so that settings may be recorded, and the heavy welding current pulses are not only accurately timed—from one to six

cycles duration—by an electronic circuit, but are also synchronised to make sure that a weld always starts at the same part of a cycle. The top and moving electrode is so mounted that there is true straight line motion between electrodes: it is carried in a low-inertia holder to give the quick follow-up necessitated by the rapid collapse of the metal being welded. The welder is foot-operated, and the sensitivity of the transmission mechanism is such that very small and delicate parts can be handled and positioned accurately. The weld switch is operated automatically only when the preset electrode pressure has been applied. An indicator gives a visual check on the completion of a weld.

The pleasing appearance of the welding machine, its compact form and the accessibility of the control are shown in Fig. 4 where an operator at the New Southgate works is welding a nickel silver residual plate to an iron relay core. The core has a chrome-on-nickel finish, and is of substantial section, whilst the plate is only 0.006 in. thick. The close-up view in Fig. 5 illustrates the operating facilities of the welder and the ample working space available. The use of a welder head which can be adjusted in height and moved radially, and the provision of an accurately machined and slotted base plate greatly facilitate the use of jig assemblies.

Lord Bennett to Open Birmingham Exchange

THE new Birmingham Exchange and Engineering Centre, which will be Britain's only permanent engineering exhibition, is to be opened by Lord Bennett on June 17th. More than 200 firms are exhibiting and all the exhibition space has now been taken.

The Effect of Quenching Strains on the Properties of an Al-Cu-Mg Alloy

By Dr. H. A. Unckel

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An investigation into the effect of elastic and plastic strain on the mechanical properties of an aluminium-copper-magnesium alloy showed the former to have little, if any, effect on ageing, but small plastic strains applied after quenching have a considerable effect on the yield stress. The subject is discussed in relation to quenching strains.

AS was shown by the work of Phillips and Brick,¹ the lattice parameter of aluminium-copper alloys after quenching from the solution-treatment temperature may be abnormally large, as a result of strains set up by the quenching. These strains affect the ageing characteristics and are dependent on the cooling rate, specimens cooled relatively slowly showing no tendency to age-harden at room temperature. Kempf, Hopkins and Irvanço,² investigated the magnitude of quenching strains in aluminium alloys, using the machining method and found that the stresses may reach the yield strength of the material. With the 51S alloy, they found stresses of 15,000 lb./sq. in. in the longitudinal direction, 7,000 lb./sq. in. in the tangential direction, and 8,000 lb./sq. in. in the radial direction; whilst the corresponding figures for the 25S alloy were 15,000, 8,000 and 12,000 lb./sq. in. Wassermann³ measured quenching strains by means of X-ray lattice parameter measurements and found them to be dependent on the diameter of the specimen. With alloys of the 24S duralumin type, he measured stresses up to 50,000 lb./sq. in. and with specimens of sufficiently large diameter—with aluminium over 0.3 in.—the yield point is reached.

Auer and Gerlach⁴ showed that the more rapid the quench, the sooner after quenching does the hardness begin to increase. Köster and Braumann⁵ confirmed these results, and found that quenching strains increase the rate of age hardening, but that the values finally attained are not affected. It is known that plastic deformation between quenching and ageing increases the yield stress and the ultimate tensile stress⁶ with alloys which are aged at moderately elevated temperatures, precipitation then taking place at grain boundaries and glide planes.⁷ Even the hardness increase on room temperature ageing is greater if the specimens are heavily deformed after quenching, as Ruehrenbech found⁸ with an aluminium-magnesium-silicon alloy. Ageing at elevated temperatures, as usually practised with this type of alloy, decreased the hardness again to a value below that obtained with specimens aged at elevated temperature without previous deformation.

Experimental Work

The present experiments were carried out with the object of ascertaining the effect of elastic strain on the mechanical properties of an alloy of the aluminium-copper-magnesium type containing copper 4.5%, magnesium 1.45% and manganese 0.6%. Complementary experiments were also carried out with plastic strain. The value of the quenching strains naturally depends on the dimensions of the specimen, the periphery which

cools first being put in compression by the contracting core, whilst the latter is under tensile strain. Specimens taken from different positions in quenched bars of sufficiently large diameter should, therefore, be in different states of strain during the ageing.

Specimens from Different Locations in Cast Billets.

A 20 in. length cut from a 7 in. diameter continuously cast billet was solution treated at 490° C. and quenched in water. Transverse specimens were cut diametrically across the billet, and longitudinal specimens from the core and the periphery. The material was in a high state of stress, and on sawing audible cracking occurred and pieces flew off. The results obtained from the tensile tests did not, however, show any differences. All values were relatively low, as is usual with cast material. The yield stress* was between 37,000 and 39,500 lb./sq. in., the specimens from the periphery giving, on the average, slightly higher values than those from the centre—39,500 against 38,000 lb./sq. in. The ultimate tensile stress was between 42,500 and 45,000 lb./sq. in. for all specimens.

Specimens from Different Locations in 4 in. diameter Extruded Rod.

From a 4 in. diameter extruded rod in the quenched and fully-aged condition, longitudinal specimens were machined from the core, the periphery and a position midway between the two. There was no appreciable difference in yield stress, ultimate tensile stress or elongation in the different positions, the yield stress ranging from 49,500–50,000 lb./sq. in., and the ultimate tensile stress from 71,000–72,500 lb./sq. in., the elongation being 12.5% in all cases.

Specimens with Different Cross-Sectional Area from 2.5 in. diameter Extruded Rod.

Two sets of test were carried out on specimens from 2.5 in. diameter extruded rod, the longitudinal specimens being taken from a position midway between the core and the periphery. In the first series, a number

TABLE I.—TENSILE TEST RESULTS ON SPECIMENS OF DIFFERENT CROSS SECTIONAL AREA MACHINED FROM EXTRUDED ROD.

| Specimen Treatment | Specimen Size (in.) | Yield Stress (lb./sq. in.) | Ultimate Tensile Stress (lb./sq. in.) | Elongation (%) |
|---------------------------------------|---------------------|----------------------------|---------------------------------------|----------------|
| Machined from rod, quenched and aged. | 1½ × 1½ | 54,200 | 78,200 | 11.5 |
| | 1 × 1 | 54,000 | 78,000 | 12.5 |
| | 0.4 × 0.4 | 53,000 | 76,000 | 14.0 |
| Machined from quenched and aged rod. | 0.7 dia. | 57,500 | 79,500 | 12.0 |
| | 0.4 × 0.4 | 53,500 | 78,800 | 12.0 |
| | 0.4 × 0.4 | 57,000 | 80,000 | 11.5 |

* Taken as the stress at 0.2% strain.

of specimens of different diameter were machined from the rod, then quenched and aged; whilst in the second series, for comparison, specimens of varying size were machined from the 2.5 in. diameter rod after it had been quenched and aged. The results obtained are shown in Table I, from which it will be seen that the size effect within this range is negligible. This was rather unexpected, and a possible explanation may be that the quenching stresses reach the yield point with the small cross sections, and thus do not increase with further increasing cross section.

Specimens from Different Locations in Extruded Rod, Machined and Tested at Intervals after Quenching.

The object of this series of tests was to study the rate of age-hardening in specimens from different positions in the rod, and, therefore, with different quenching strains. Specimens with 0.5 in. square cross section were machined from the centre and the periphery of 4.5 in. diameter extruded rod at varying intervals of time after quenching. With rod of this size, overnight homogenising at 490° C. was necessary in order to dissolve residual eutectic in the structure. The results of mechanical tests on these specimens are shown in Table II. There is no essential difference between the values for specimens from the centre and from the periphery as regards quenching strain effects. The strength of specimens from the periphery is usually somewhat less because of coarser grain structure. It is remarkable, however, that ageing is almost complete after a few hours with this extruded rod. Normally the period for full ageing with alloys of this type is several days. It may be, therefore, that quenching strains have accelerated the ageing process, but it appears to be immaterial whether the strains are compressive or tensile, since specimens from centre and periphery gave about the same values.

With overnight homogenising, the yield stress was 38,000 lb./sq. in., and the ultimate tensile stress 59,500 lb./sq. in., as compared with 53,000 and 75,000 lb./sq. in., respectively, after homogenising for a long period before quenching and ageing. This result is rather surprising in view of a previous investigation of the author,⁹ in which it was found that an extra homogenising treatment had no appreciable effect on tensile properties. In the present investigation, with an extruded rod diameter of 4.5 in. as compared with 4 in. in the earlier experiments, the reduction of area on extruding from the billet diameter to the rod diameter is somewhat less. This may have a bearing on the matter, as the smaller the diameter of the extruded rod for a given size of cast billet, the greater is the degree of working, the finer the distribution of the eutectic, and the shorter the time necessary to take this eutectic into solid solution in subsequent solution treatment or homogenisation (although other intermediate phase constituents may be left undissolved).

At least three factors determine the rate of homogenisation: (1) the degree of reduction; (2) the fineness and degree of homogenisation of the cast billet structure; (3) the type of billet. The comparatively high strengths obtained in the earlier experiments referred to above, in spite of the low degree of reduction, were presumably the result of an exceptionally fine structure in the cast billet. It is common commercial practice to homogenise cast billets overnight, and to give a further overnight homogenisation, after extrusion, to rods of over 3 in. diameter, depending on the degree of reduction. In the United

TABLE II—TENSILE TEST RESULTS ON SPECIMENS FROM DIFFERENT LOCATIONS IN EXTRUDED ROD, MACHINED AND TESTED AT INTERVALS AFTER QUENCHING

| Ageing Period (hr.) | Specimen Location | Yield Stress (lb./sq. in.) | Ultimate Tensile Stress (lb./sq. in.) |
|---------------------|-------------------|----------------------------|---------------------------------------|
| 1.5 | Centre | 51,000 | 75,500 |
| | Periphery | 49,000 | 75,000 |
| 2.5 | Centre | 44,000 | 67,000 |
| | Periphery | 43,000 | 68,000 |
| 4.5 | Centre | 47,000 | 70,000 |
| | Periphery | 45,000 | 65,500 |
| 17.5 | Centre | 48,000 | 72,500 |
| | Periphery | 45,000 | 65,500 |
| 96.0 | Centre | 54,000 | 77,500 |
| | Periphery | 55,500 | 79,000 |
| 264.0 | Centre | 52,000 | 76,000 |
| | Periphery | 49,000 | 71,500 |

States, a high degree of reduction is recommended—a ratio of container diameter to rod diameter of at least 8:1. Further investigation of the state of homogenisation and the effect of reduction on extrusion would be of great value.

Specimens Aged under Elastic Tensile Strain.

The material used for this set of tests was in the form of 0.25 in. diameter wire, the gauge length being turned down to 0.2 in. Immediately after quenching, the specimens were clamped in the grips of a tensile testing machine or of a special spring device, and subjected to a definite elastic strain. For comparison, in each test, a second specimen was aged for the same time without strain. The results were somewhat erratic, but on the average specimens held under a stress of from 0.7 to 1.0 times the yield stress showed an increase in yield stress of 4,000—5,500 lb./sq. in., when tested after straining for periods ranging from several hours to several days. The difference between the strained and unstrained specimens was almost constant during the ageing period, when the yield stress rose from 20,000 to 43,000 lb./sq. in., and the ultimate tensile stress from 50,000 to 70,000 lb./sq. in. With some of the strained specimens, however, there was no rise in yield stress, and it appears probable that the yield stress increase is actually due to some small plastic deformation resulting from slight bending effects caused by somewhat eccentric loading in the machine. Furthermore, strain distribution differs in the different grains according to their orientation, and in some excessively oriented grains the yield stress may even be surpassed. This effect of course ought to be the same in all specimens.

Specimens Quenched under Restraint.

This series of tests was intended to show the effect of strains set up in specimens quenched under restraint, i.e., not allowed to contract: tensile stresses were thus created. In the earlier experiments, specimens were clamped with screws in an iron frame and heat-treated together with the frame, but the screws loosened at the solution treatment temperature of 495° C., and it proved more satisfactory to provide specimens with protruding lugs which were held in corresponding cut-outs in the frame. The yield stress of specimens quenched in this way was about 4,000 lb./sq. in. higher than that of specimens quenched without restraint. The ultimate tensile stress and elongation were about the same in both cases.

Specimens Deformed Plastically immediately after Quenching.

Immediately after quenching, one of each pair of specimens was stretched 1% in a tensile testing machine,

TABLE III.—TENSILE TEST RESULTS ON SPECIMENS DEFORMED PLASTICALLY IMMEDIATELY AFTER QUENCHING.

| Treatment | Interval between Straining and Testing (hr.) | Yield Stress (lb./sq. in.) | Ultimate Tensile Stress (lb./sq. in.) | Elongation (%) |
|-----------------|--|----------------------------|---------------------------------------|----------------|
| Strained | 3 | 36,500 | 59,500 | 21 |
| Unstrained .. . | | 25,500 | 57,000 | 22 |
| Strained | 6 | 40,000 | 52,000 | 20 |
| Unstrained .. . | | 32,500 | 62,500 | 20 |
| Strained | 48 | 44,500 | 65,000 | 23 |
| Unstrained .. . | | 35,000 | 65,000 | 23 |
| Strained | 96 | 47,000 | 66,500 | 20 |
| Unstrained .. . | | 34,000 | 69,000 | 20 |
| Strained | fully-aged | 54,000 | 73,000 | 21 |
| Unstrained .. . | | 43,000 | 72,500 | 23 |

the strain being measured with an extensometer. The other specimen of the pair was not strained and the values obtained on testing the pairs after varying intervals of time are set out in Table III.

As will be seen, the yield stress of the strained specimens exceeded that of the unstrained ones by 8,500–11,000 lb./sq. in. In the course of ageing, the yield stress rose from 36,500 to 54,000 lb./sq. in., with the strained specimens, and from 25,500 to 43,000 lb./sq. in. with the unstrained specimens, the difference remaining approximately constant during ageing. The ultimate tensile stress and elongation were not affected by such straining as was applied in these experiments. The effect of plastic strain after quenching and before ageing is partly one of strain-hardening by cold work, but to a greater extent it has an accelerating effect on the precipitation process, since atom displacement by deformation assists the structure to attain equilibrium, i.e., to form precipitated phases from the supersaturated solid solution. Plastic strain acts in this case in much the same way as elevated temperature ageing in increasing atom mobility. Cold working between quenching and ageing is sometimes practised with alloys which age-harden at elevated temperatures, in order to intensify the hardening—in copper-beryllium alloys, for example. In the case of alloys age-hardening at room temperature, such as the aluminium-copper-magnesium group, plastic straining after quenching is not usually applied. As does ageing at elevated temperature, plastic straining may in such cases induce actual precipitation and agglomeration of precipitated particles, with correspondingly reduced corrosion resistance. As reported by Teed,¹⁰ a small amount of plastic strain increases the yield stress but decreases the ultimate tensile stress. With greater amounts of cold work, the elongation is reduced. Cold work applied to material in the fully-aged condition increases both the yield stress and the ultimate tensile stress, but decreases the elongation considerably. In passing, reference may be made to the fact that material which has been lightly cold worked, tends to develop a coarse grain size if it is later heat treated for a second time.

Specimens Deformed Plastically immediately before Quenching.

For these tests two specimens were bent, attached to a fixture and solution treated. Immediately before quenching, the specimens were straightened whilst still in the furnace, and then water quenched. Another parallel set of specimens was not deformed, and after ageing for about a week the average yield stress of the deformed specimens was 41,500 lb./sq. in., as compared with 42,500 lb./sq. in. for the undeformed ones, the corresponding ultimate tensile stresses being 68,000 and

66,500 lb./sq. in. Deformation before quenching has thus no appreciable effect, since recovery and recrystallisation take place very rapidly at 500°C.

Conclusions

With the alloy in question, elastic strains had only a minor, if any, effect on ageing, but small plastic strains applied after quenching had a considerable effect on the yield stress. After an initial rapid rise, the subsequent rate of rise in hardness seemed to be about the same with both strained and unstrained specimens. The experiments with cast and extruded rod did not show the differences with specimens from different parts of the rod which might be expected on the basis of considerable overall strain above the yield stress with ensuing slight plastic strain.

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The Immortality of Steel

THE story of the Steel Scrap Drive, without which the steel industry of this country could not have achieved such remarkable results in recent years, is told in a publication issued by The British Iron and Steel Federation with the title: "The Immortality of Steel." Britain is now comparatively clear of much recoverable scrap which was lying uncollected before the campaign was launched, for during the Steel Scrap Drive every possible source was exploited and made to yield its quota. There must be a fund of interesting stories in the reports of the District Committees, if the few which it is possible to refer to in the booklet are any indication. There is the story of the recovery of the steel used by the Germans to fortify the Channel Islands, which totalled some 7,000 tons, and that of the 350 tons of valuable material contained in disused steam plough engines whose farmer owners were loth to part with their old friends, but perhaps the strangest project described is the recovery of 1,500 tons of biscuit tins dumped in a disused quarry in Yorkshire. In the course of three years, one and a half million tons of extra scrap have been recovered and, as a result, stocks of scrap are now up 50%, the steel industry has been tided over a difficult supply period, and now with rapidly expanding pig iron production, the pressure is relieved. The intensive effort to clear dormant scrap had to end sometime: there is not an indefinite supply of tramrails; nor can slag heaps be made to yield more scrap than they contain. Although the main drive is finished, its main purpose completed, the organisers feel that it will not be without lasting benefit, in that it has made people more conscious of the need for scrap in maintaining steel output.

B.I.C.C. Electrode Tips

BICALLOY electrode tips continue to be manufactured by British Insulated Callender's Cables, Ltd. Although the manufacture of their resistance welding and heating machines was recently taken over by Metropolitan-Vickers Electrical Co., Ltd. Bicaloy welding tips, are still made and supplied by B.I.C.C.

A Survey of Applications of British Industrial High Frequency Induction Heating Equipment and their Economic Aspect

This article is a slightly abridged version of a paper presented to the IIIe Congrès International D'Electrothermie in Paris last year. The paper is the joint effort of a group of manufacturers of high frequency heating equipment forming part of the British Electrical and Allied Manufacturers' Association, and in the choice of examples to represent each field, special weight has been given to those applications which clearly demonstrate the economic saving resulting from the introduction of this relatively new technique.

THE application of high frequency induction heating* has made rapid strides in recent years, and apart from its use for melting and surface hardening, it is now finding application in the heating of forging stock, through hardening, brazing and silver soldering, soft soldering, vacuum melting and hot pressing of metal powders. In the following pages, particulars will be given of applications in each of these fields, and in making the choice of examples special weight has been given to those applications which clearly demonstrate the economic saving resulting from the introduction of this new technique—whether this saving is brought about by an increased rate of production, ability to employ cheaper labour, or the elimination of other operations which it would be necessary to perform if other forms of heating were employed.

Industrial High Frequency Generators

The majority of induction heating applications require a source of electric power at some frequency considerably higher than that of the normal mains supply. Generators or converters are now available for frequencies ranging from a few hundred to millions of cycles per second. Motor driven alternators are used up to 10,000 cycles per second, and thermionic valve oscillators for the higher frequencies. High frequency alternators are mostly of the inductor type, having no rotating windings. Both homo and heteropolar constructions are made; the principal operational difference between them is the very much more rapid field response (shorter time constant) of the latter. The continuous development towards more completely automatic control of induction heating processes is assisted by this advantage of the heteropolar machine. Thus in the operation of H.F. melting furnaces for example, automatic switching of furnace capacitors may be carried out more quickly, furnace power being interrupted for only one or two seconds and then restored to the predetermined value. Some form of automatic H.F. voltage regulator is nearly always used, with which alternator output voltage is maintained constant within, e.g., $\pm 1\%$ from no-load to full load.

Both motors and alternators are commonly arranged for duct ventilation, and the tendency now is towards closed circuit ventilation, in which the hot outgoing air from the machines is ducted to water cooled heat exchangers and then recirculated. This system ensures cleanliness in the machines and greatly reduces noise. Even so, installation of the motor-alternator set in a

TABLE I.—INDUSTRIAL HIGH FREQUENCY GENERATORS.

| Type of Generator | Frequency Range, kc/s | Power Range Output, kW | Principal Applications |
|----------------------|----------------------------------|---|---|
| H.F. Alternator | 0.5 to 10 | 20 to 1,500 at 1 kc/s to 3 kc/s 10 to 300 at 10 kc/s | Melting, billet and bar heating, (e.g., for forging) brazing, hardening, tempering. |
| Valve Oscillator | 100 to 5,000 commonly 300 to 500 | 1 to 200, commonly 2 to 25 | Local and surface hardening, soldering, brazing. |
| Spark-Gap Oscillator | 20 to 300 | 3 to 20 | Melting of small charges, ferrous and non-ferrous. |
| Inverter | 0.5 to 2 | 150 to 300 | Melting, heating for forging. |

separate sub-station is generally preferred, especially in foundry practice.

Valve oscillator type H.F. generators are available with power output ratings up to at least 200 kW. Many of the lighter heat treatment applications, and particularly the surface and local hardening which is their principal field, are adequately catered for with output power ratings up to 25 or 50 kW, and in the frequency range 300 to 2,000 kc/s. The use of inductively coupled output circuits is favoured, in which the possibility of H.T. D.C. power being fed to the work circuit under fault conditions is eliminated. Automatic time control is easily applied to valve type generators; this is an important point, as some applications require power to be applied for as little as a fraction of a second. Automatic control of power level, and adjustment to offset mains voltage variations, may also be incorporated.

Heat due to losses in the generator, and particularly in the valves, is removed either by air blast or water cooling; a closed recirculatory system with a cooler may be used in the latter case, particularly where the local water is hard.

Although nearly all industrial high frequency power used in Britain is generated by either alternators or valve oscillators, two other types of generator must be mentioned. The spark-gap oscillator, with a useful output power rating from 3 to 20 kW, is a convenient and relatively cheap H.F. source for small melting furnaces and some brazing work. The inverter (i.e., inverted rectifier) is a possible alternative to the alternator at frequencies up to 2,000 cycles per second, but has not yet proved itself. The principal features of the available generator types are summarised in Table I.

* The term "high frequency" implies the use of a generator or frequency converter by which a frequency higher than that of the supply mains is produced.

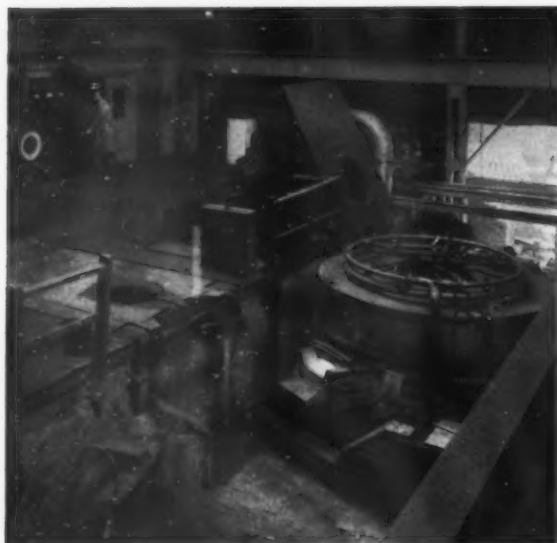


Fig. 1—650 kW 1 kc/s melting installation for high quality cast irons.

Melting

The use of the "coreless induction furnace" for making high quality alloy steels is, of course, well established. Nickel-chromes and particularly such alloys as the Nimonics are also produced largely in high frequency furnaces. The production of high quality cast irons for piston rings and cylinder liners, and the reclamation of cast iron by the remelting of borings, are carried out in H.F. furnaces. Fig. 1 illustrates a recent 650 kW installation consisting of two furnaces each of 2-tons capacity for melting cast iron, including a large proportion of borings. The metal from either furnace may be transferred by means of a launder to the 10-tons capacity gas-fired holding furnace seen in the foreground in Fig. 1.

A homopolar generator is used, rated at 650 kW, 1,300 V, 1,000 c/s, 2,900 r.p.m. driven by a 980 h.p., 6,300 V, 3-phase, 50 c/s double squirrel cage motor, arranged for pipe ventilation. The generator sub-station is provided with forced ventilation, with air filters and fan rated at 11,000 cu. ft./min.

Each furnace is rammed with a standard acid lining material, with an earth pole in the base. The pole is part of an earth leakage relay system which indicates the amount of leakage current, thereby giving warning of a worn or dangerous lining and switching off the power. The two furnaces are connected through a changeover switch to the capacitor bank and generator.

The acid lining is fritted in the usual manner using a steel former. For the fritting heat the steel former is filled with heavy pieces of cast iron carefully packed in to give a compact mass; the first fritting heat takes about 5-hours. Subsequently, the furnace is charged with a mixture of borings, pig iron and foundry scrap. The borings are wet with cutting oil solution and so an endeavour is made to keep the charge as open as reasonably possible to allow the vapours to discharge freely. When melted a chill sample is taken and from this an adjustment is made of the carbon and silicon content, if necessary. The total charge is 4,700 lb., the melting

time in a hot furnace is 2½ hours and the yield 87%. The average consumption is 720 kWh/ton and a lining life of about 100 heats can be expected.

In addition to melting a higher proportion of cast iron borings, the advantages of the high frequency furnace over the cupola, which is the cheapest means for melting cast iron, are the improved metallurgical control available and especially the avoidance of sulphur pick-up which normally occurs in the cupola. Compared with the arc furnace the conversion costs are lower, due mainly to the absence of electrodes.

Use is being made of high frequency heating for melting relatively small quantities of special nickel-chrome steels for precision casting by means of the lost wax process, and valves oscillators operating at about 400,000 c/s provide a convenient power source for the relatively small furnaces used.

With this technique, quantities of 10 to 20 lb. are generally melted to a temperature of 1,650°C., after which a hot mould is clamped on the top of the melting unit and the entire assembly is turned upside down, the hot metal then being forced into the mould. The great advantage of melting by high frequency is that alloys of very high purity are attainable without introduction of carbon. In addition, the short heating times obtained permit closer tolerance in the alloys. Using a 25 kW generator, melting times of 18 min. for 20 lb. of special alloy steel are obtained. An alternative to the Durville method of inverting the furnace and mould assembly, is to spin the crucible with the mould clamped to it so that the metal is fed into the mould by centrifugal force.

For the larger quantities sometimes required for precision casting involving weights of 100 lb. or more, motor-alternators are preferred as the power source. They are also used exclusively by the permanent magnet industry for the melting of magnet steels, the relatively low frequency giving sufficient stirring to produce a homogeneous casting from elements of widely different specific gravities.

Through Heating

It may seem harder to be able to justify the high cost of high frequency heating equipment for forging than for melting, since alternative gas, oil or coal fired furnaces are available, and there is no very difficult refractory problem at forging temperatures, i.e., 1,150 to 1,250°C. It is therefore not surprising that, in the case of two of the most successful high frequency installations in forges, the managements concerned were chiefly interested in improving working conditions. No other form of heating makes possible so much improvement in this direction as does induction heating, and the design of the building which houses the largest press-forging installation in Britain was based upon the use of high frequency power.

In practice, however, it has been found that high frequency induction heating, properly applied, also results in cheaper production costs. This is due mainly to four factors, namely:

- The high degree of heater mechanisation which is possible with induction heating, when applied to high speed repetition forging.
- The high efficiency of this method of heating. From 50 to 66% of the electrical mains energy is usefully retained in the hot steel as discharged from the heater.
- The extremely short starting up time required by the induction heater, with no heater stand-by losses.

(d) Scale formation during heating is minimised by rapid heating, and forging die life is consequently prolonged.

Induction heating speeds for steel billets may be very rapid. Fig. 2 shows average through heating times for both round and square sections, and the corresponding H.F. power rating (i.e., generator rating) per inch length of coil. The curves refer to plain medium carbon or low alloy steels; high alloy steels have a lower thermal diffusivity and may require up to 50% longer heating time.

In an installation for heading cut lengths of round steel bars, in the manufacture of black bolts in diameters from $\frac{1}{2}$ in. to $\frac{3}{4}$ in., ten automatic induction heaters supply five double sided heading presses with steel pins, heated to $1,250^{\circ}\text{C}$. at one end for a specified length. The average output per heater is 1,250 pins per hour, and the average power consumption of each heater is 45 to 50 kW at 500 V, 10 kc/s. This shop was specially designed for the use of these automatic heaters, and its floor is on three levels. The loading level is convenient for placing supplies of cropped pins in the magazines of the heaters. Heaters, heading presses and trimming presses are on a lower level, and below this again is the final discharge into trucks.

The 600 kW high frequency generator station for this installation contains two 300 kW 10 kc/s motor alternator sets, with automatic H.F. voltage control, closed circuit ventilation and pump-lubricated Michell pad bearings. The 400 V. motors are started by direct-online contactors on the primary side of the H.T. transformers.

The other example of heating for forging to be described is probably the most interesting, and the largest, in Europe. The two high frequency sub-stations generate respectively 900 kW of 10 kc/s power and 2,400 kW of 3 kc/s power. There are six 10 kc/s heaters each rated at 150 kW, in the press forge, and six 3 kc/s heaters rated variously from 250 to 800 kW. All these twelve heaters use a rotary hearth carrying billets through a channel type coil, and heater outputs range from 1,000 lb. to over 2 tons per hour. The mechanised heaters, in conjunction with forging presses, give outputs in numbers of forgings per hour of from 100 to 600 or more, depending upon the billet size and weight. The whole installation has a potential production of 8 to 10 tons per hour. Maintenance on forging presses and dies is necessarily heavy, but the normal availability of the forge is 65 to 70%. Breakdown time due to heater faults is consistently below 1.5%. Mains energy consumption is 450 to 475 kWh/long ton with optimum billet sizes; average consumption for all sizes, allowing for reheated billets, press stoppages etc., is 630 kWh/ton, or £2.7/ton at 0.9d. per kWh.

As already mentioned, the largest forging press is supplied with billets (mostly 4 in., $4\frac{1}{2}$ in. and 5 in. square section and up to 10 in. long), heated in an 800 kW 3 kc/s rotary heater. A second heater also rated at 800 kW is installed alongside for heating bars up to 42 in. long and 3 in. square, for forging axle beams, crankshafts, etc. The latter heater has four magazines, two on each side, and heated bars are discharged automatically on to a driven roller conveyor which carries them to the press.

In the 10 kc/s sub-station, three 300 kW generators are installed, with starter equipments and H.F. cubicles containing main contactors, automatic voltage control equipment and alternator series capacitors. H.F. power

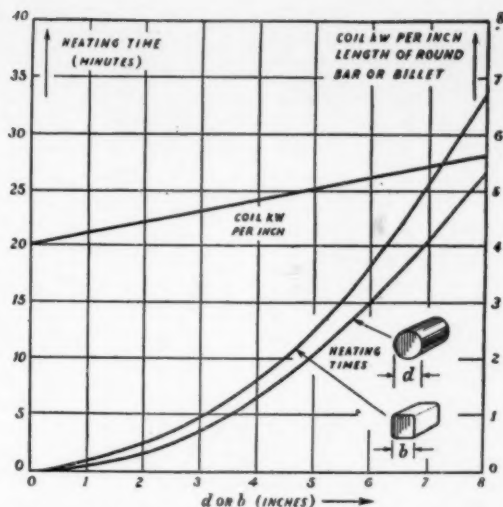


Fig. 2.—Average through-heating times for round and square steel sections.

is transmitted to heaters in the forge by underground lead covered co-axial cables. Control of power to each heater is carried out from a cubicle in the forge, alongside the heater; this also contains instruments showing heater kW, volts, amperes, reactive kVA, rotary hearth speed, etc.

Through-hardening of bar steel stock has as yet had only a very limited application in Britain, although recent research indicates that there is an advantage to be gained from the use of higher tempering temperatures and shorter tempering times to which the induction method is particularly well suited. An installation for through hardening bar stock from $\frac{1}{2}$ in. to $1\frac{1}{2}$ in. diameter has two coils covering the range of bar sizes, the larger coil having a bore of $2\frac{1}{4}$ in. for bars from $\frac{3}{8}$ in. to $1\frac{1}{2}$ in. diameter, and the smaller coil having a bore of $1\frac{1}{4}$ in. for bars $\frac{1}{2}$ in. to $\frac{3}{4}$ in. diameter. The same coils are used for both hardening and subsequent tempering during a second pass. One size of quench-rose only is used, and this of course is cut off when bars are being tempered. Bars are rotated while being progressed through the machine to prevent distortion, and a very high degree of uniformity is obtained among bars treated by this method. The high frequency supply is from a 10 kc/s 100 kW alternator driven by a 180 h.p. motor. A $\frac{1}{2}$ h.p. motor drives three sets of rollers through a variable ratio gear box. Hardening speeds vary between 28 in./min. for $1\frac{1}{2}$ in. diameter shafts and 56 in./min. for $\frac{3}{4}$ in. diameter shafts, though only half of the available power output is used for the latter size and speed. The weight of bar hardened per kWh of mains energy used varies from 6.1 lb. for $\frac{1}{2}$ in. diameter shafts, to 9.3 lb. for 1 in. diameter shafts, falling again to 7.6 lb for $1\frac{1}{2}$ in. diameter shafts. Tempering speeds are slightly lower than for hardening, and corresponding coil power input is also considerably lower, while mains energy consumption corresponds to an average of 16 lb. of steel tempered per kWh.

The next example of through heating to be described is the localised annealing of clock springs. The spring strip is fed from a continuous coil through a single turn inductor of the required length and thence to the cropping press which is located a number of spring lengths away.

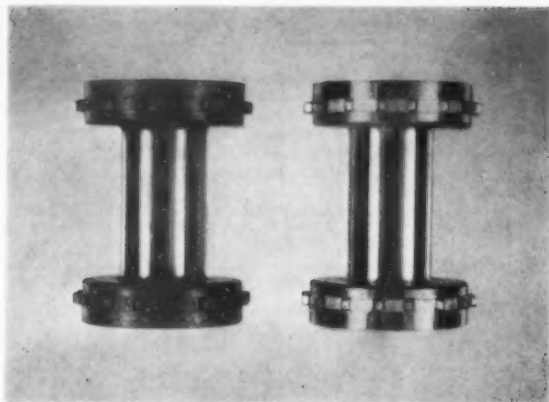


Fig. 3a—35 mm. film sprocket, with H.F. hardened teeth.

Fig. 3b.—Section showing extent of hardening.

The cropping and heating of the spring occur simultaneously, the heating time being 0.25 seconds. A 2½ kW valve oscillator type of generator is used, and the production speed obtained is 60 springs per minute. A very high degree of uniformity is obtained by this method, and the introduction of high frequency heating has resulted in a 100% acceptance of the product. Torch annealing for this application had previously resulted in a large reject percentage as well as premature failure of the springs.

Finally, through-heating is sometimes employed where surface hardening is required, but surface heating presents difficulties. An example is the internal hardening of tractor link bushes, which are through-heated and quenched on the inside to give the necessary hardened surface.

Surface and Local Hardening

Surface hardening by means of high frequency induction heating has been very widely applied in Britain, particularly in the motor car industry and other light engineering industries employing mass production methods, such as for example in the manufacture of refrigerators.

Here the well-known "skin effect" of high frequency current is beautifully exploited, by means of very high power concentrations, to raise the temperature of a thin surface layer of the work-piece to hardening temperature before the interior is heated appreciably by thermal conduction. The part is then quenched to give a hard surface without altering the previous heat treatment of the core. The process can be applied to carburised parts,

but it is used principally in conjunction with plain medium carbon steels, having a carbon content of 0.35–0.6%.

The hardened layer depth required for most light engineering components, such as shafts, cams, etc., used in the automobile industry, is from 0.030 in. to 0.100 in. The thinner cases can be obtained either by raising the frequency or the power input per unit of surface area. For the smaller components, the first solution is the more economical; many automobile and similar components are surface hardened today, and in many instances the H.F. power supply is from a valve-oscillator type of generator within the output power range from 5 to 30 kW, and frequency range 300 to 2,000 kc/s. In other instances, where power from 10 kc/s alternators is available, a thin case is obtained by an increase of power and consequent reduction of heating time.

Power concentrations from 5 to 20 kW/sq. in. of surface to be hardened are commonly used. Thus, where a small surface area is to be treated, such as a cam or the working faces of a selector fork the whole area is heated in a "single shot," the heating time being only of the order of a few seconds. The surface of a long shaft, on the other hand, must be treated progressively, all the available H.F. power being concentrated on a relatively small area at a time. The shaft is passed through the heating inductor and thence through a spray quench, at a controlled speed somewhere around 1 in./sec. in the case of a ½ in. diameter shaft and a 20 kW H.F. oscillator. In this way components of large area are hardened using generators of very modest size. Satisfactory results are obtained on components of varying section by suitable adjustment of speed and power.

The principal advantage of the induction hardening method is that semi or fully automatic equipment can often be used. This equipment fits into the production line, and handles components singly and at high speed. Moreover unskilled labour may be employed on such automatic machines. The examples discussed illustrate this machine tool approach.

In an installation for surface hardening the piston rods of motor car shock absorbers, plain medium carbon steel piston rods, ½ in. diameter, are hand loaded into the machine, through which they move continuously at constant speed and each rod is surface hardened by the progressive method over an accurately controlled portion of its length. The variable speed electric drive is adjusted to suit work diameter and hardened depth required. The rods are rotated during their passage through the inductor and quench by means of skewed rollers incorporated in the drive mechanism. A 25 kW H.F. output valve oscillator operated at approximately 350 kc/s supplies the high frequency power, and the feed rate for the work-pieces is approximately 1½ in. per second. The outputs achieved are 950 rods per hour, each rod 6½ in. long with 4½ in. hardened length; alternatively, 650 rods per hour, each rod 9½ in. long and 7½ in. hardened length. Total operating costs for the machine, including depreciation, energy and labour, and cooling water, are 10/6d per hour or 0.13d. per shaft at 950 shafts per hour. The principal advantages of this method are:—

- Only one comparatively unskilled operator required.
- The heat treatment is incorporated in the production line and replaces the conventional batch furnace method.

(c) Reduced distortion (a maximum of 0.0015 run-out on $9\frac{1}{2}$ in. length) and reduced scaling. Only a very light grinding is required after hardening, to prepare the surface for chromium plating.

In an installation for surface hardening motor car engine cam shafts, the shafts are hardened in three stages corresponding to the three stations:—

- (a) Bearings.
- (b) Cams.
- (c) Gears.

They are loaded in pairs by hand in each station in turn. Shafts in stations (a) and (b) are moved vertically through the inductors, dwelling on each area for a pre-determined heating time, and then quenched. The power source is a 100 kW 10 kc/s motor generator set, and two complete shafts are obtained every 90 seconds. This method replaces the conventional pack carburising process which is both lengthy and expensive. Fewer and less skilled operators are required and there is a considerable reduction in floor space. Operation times are:—

| Part | Cam | Eccentric | Gear | Bearings | | |
|---------------------------------------|-----|-----------|------|-----------|-----|---------|
| | | | | Small End | Mid | Big End |
| Heat (sec.) | 2.5 | 2 | 3 | 7 | 7 | 10 |
| Quench (sec.) . . . | 5 | 5 | 2 | 10 | 10 | 10 |
| Quench Pressure (lb./sq. in.) | 20 | 20 | 12 | 38 | 38 | 38 |
| Delay (sec.) | 0.2 | 0.2 | 0 | 0.2 | 0.2 | 0.2 |

An example of localised through hardening of a small component is illustrated by a 35 mm. film sprocket on which the two rings of teeth are heated, one at a time, using a $2\frac{1}{2}$ kW valve oscillator type generator and a heating time of $3\frac{1}{2}$ seconds, followed by an oil quench. The hardness obtained is 810 V.P.N. and the great advantage with high frequency heating is in the complete avoidance of distortion of the bore. The older method of hardening the whole sprocket resulted in 50% rejects, whilst top quality and 100% acceptance is obtained with the H.F. method.

Another example of local hardening is a small shaft of a windscreen wiper motor, made of mild steel which has been gas carburised. The shaft is through heated locally to a temperature of approximately $780^{\circ}\text{C}.$, but hardening is confined to the parallel portion. The heating time is 3 seconds followed by a water quench, and the power supply is a $2\frac{1}{2}$ kW valve generator. A hardness figure of 900 to 940 V.P.N. is obtained.

For the surface hardening of small gear wheels used in electric drills, etc., a 17 kW (output) 450 kc/s valve generator is used and, with unskilled labour, the equipment will harden and temper 1,000 small gears per hour. The same quantity takes about 6 hours when treated in a salt bath by a skilled operator. This equipment was originally installed to treat nine types of component, and has since been used on about sixty, including gears, pinions and shafts. The H.F. method has reduced distortion and scaling, and eliminated the need for a grinding operation after hardening.

The equipment is installed, as is now standard practice, on the machine shop floor, in the production line, and consists of H.T. transformer and rectifier unit, H.F. oscillator unit, oil quench tank and oil cooler, and the workhead unit mounted above the quench tank.

Gears from $\frac{3}{8}$ in. to $4\frac{1}{2}$ in. diameter are treated, also pinions and cluster gears forged integrally with their



Fig. 4.—Small parts soft-soldered by H.F. on conveyor belt.

shafts. They are first hardened, to a depth slightly below the tooth root, and then tempered to a degree depending upon the duty.

Quickly interchangeable jig panels cover the range of parts. Each part is hand loaded onto the jig, which then slides upwards to offer the part to the inductor; after the appropriate heating time, the part is automatically dropped from the jig into the quench oil, where it is collected in a basket. Interlocks ensure that the part must be properly located in the inductor, and a guard-door closed, before H.F. power can be switched on.

Brazing and Silver Soldering

Several H.F. installations are in operation for brazing or silver soldering assemblies of two or more parts, applications include tipping of tools with hard carbide cutters (lathe tools, milling cutters, rock drills, etc.), joining twist drills to shanks, and fabricating machine parts. Two joints on an automobile shock absorber are brazed simultaneously using a 375 kc/s, 10 kW output valve generator and 60 assemblies (120 joints) are produced each hour. A 2-station unit is used, with a changeover switch, one station being unloaded and reloaded while brazing is in progress at the other; this arrangement gives the equipment a high utilisation factor.

The advantages of using H.F. heating for such work include:

- (a) Unskilled labour can be employed.
- (b) Consistent quality of joints.
- (c) Reduced scaling and distortion. Where these factors are particularly important, or grain growth of the steel is to be avoided, silver solders are used in preference to brass.

Soft Soldering

H.F. heating for soft soldering has proved very successful, particularly in those cases where heating must be localised (and therefore rapid) in order to avoid damaging adjacent non-metallic material, or to avoid annealing the metal itself.

In a machine for soldering end-caps to the cylindrical brass bodies of automobile ignition capacitors, flux-cored solder is applied as a preformed ring and the assemblies are placed by hand into spring-loaded jigs on the

6-station work-table, which is indexed by a Geneva star mechanism. An interesting feature is that each station has its own inductor, and this is automatically connected to the H.F. supply when indexed to the heating position. The soldered assembly is automatically ejected down a chute. A $3\frac{1}{2}$ kW generator, frequency 450 kc/s, is used, and the output of 360 capacitors per hour is three times that obtained by the same operator using a soldering iron. Also the heating is so local and rapid that the wax-impregnated paper dielectric of the capacitor is quite unharmed.

For the soldering of a brass tube into a brass hub, for telephone equipment, a simple handloaded fixture is used in conjunction with a 5 Mc/s 2 kW generator, giving an output of 140 joints per hour, seven times as high as the acetylene torch method it displaced. In addition, the brass tube is not now annealed in the process, and unskilled labour can be employed; to avoid annealing in the old method, a water jacket had to be used. Many small components may be soldered at the rate of hundreds or thousands per hour on a moving conveyor belt. Typical examples include the following:

(1) For soldering a cycle lamp switch knob (a pressing) to the brass spindle, the latter is flux-dipped and dropped into the pressing with a ring of solder wire. These assemblies are carried through an inductor at a belt speed of 5 ft./min., and an output of 2,500 per hour obtained.

(2) Radio components consisting of bakelite plates carrying phosphor bronze springs or pins and connector strip are soldered with the aid of 22 s.w.g. cored solder wire for the former, and solder paint for the latter. Hourly outputs from the conveyor belt are respectively 1,440 and 4,800.

(3) Before soldering an electro-tinned brass cap to a ceramic bush, the latter is pre-silvered and tinned. An asbestos "boat," drilled to locate the caps, acts as a jig and 22 s.w.g. cored solder is used: an output of 5,760 assemblies per hour is achieved.

Vacuum Applications

Applications of vacuum techniques to high frequency heating are as yet almost entirely confined to metallurgical research. During the war, magnesium reduction and distillation plants were operated, but these have been dismantled as uneconomic for normal conditions. Some vacuum sintering of hard metal powders and vacuum melting of special alloys are being carried out on a production scale. A well-established production process involving H.F. heating in vacuo is the heating

of radio valve parts for the purpose of driving off occluded gases; no other satisfactory method is available.

In metallurgical research, vacuum H.F. heating is applied to melting and casting metals of very high purity; for the removal of dissolved gases from metals; and for the analysis of these gases. The vacuum vessel of a melting installation in an industrial research laboratory, for work on the physical properties of materials for electrical steel sheets, is water-jacketed, has a stainless steel lining, and contains a 10-25 lb. tilting furnace, a copper-lined water-cooled mould, and mechanisms for making alloy-additions during melting, and for pouring into the mould. These mechanisms are controlled by external hand-wheels. There is a large control panel for the H.F. supply to the furnace, obtained from a 25 kW, 10 kc/s, 250 V, alternator set, and a small panel containing thermocouple and ionisation vacuum gauge equipment. The rotary backing pump has a capacity of 100 cu. ft./min. and the booster diffusion pump has a maximum pumping speed of 500 litres per second at 10 microns Hg.

A unit for vacuum melting and casting iron in quantities up to 25 lb. is installed in the National Physical Laboratory, Teddington. Selected iron is first melted in an open H.F. furnace of 75 lb. capacity; a 30 kW, 5 kc/s supply is used, and melting takes about 90 min. The metal is kept molten for about 1 hour to reduce carbon content, the surface being frequently skimmed. Nitrogen or argon blown onto the melt after this oxidising treatment removes carbon monoxide. The oxidised iron ingots from this furnace are machined to remove scale, and remelted in the vacuum furnace. Melting down is done in hydrogen at about 10 cm. Hg. pressure to prevent spurring from gas evolution. When the charge is fully molten, hydrogen is removed, and the melt held in vacuo (about 0.05 mm. Hg.) to reduce the carbon content. Then dry hydrogen at atmospheric pressure is blown across the surface of the melt to remove oxygen. Finally hydrogen at 5 cm. Hg. is maintained for 30 minutes and the melt poured at this pressure. An interesting point is that the furnace coil input power for holding the charge at temperature has to be doubled during the hydrogen blowing stage, because of the high thermal conductivity of the hydrogen. A detailed account of the melting procedure, and of chemical analysis and physical tests, has been published elsewhere.*

A high frequency vacuum fusion method has been developed by the National Physical Laboratory for the determination of oxygen, hydrogen and nitrogen in metals.† The apparatus is shown diagrammatically in Fig. 5 and consists essentially of a graphite crucible surrounded by fine graphite powder in a silica sleeve, which in turn is surrounded by a glass tube for water-cooling. The inductor coil surrounds the latter and is fed from a 30 kW, 5 kc/s motor generator equipment, the primary purpose of which is to feed the vacuum melting installation mentioned above. This coil is rated at 2 to 5 kW depending on requirements.

The mouth of the crucible is closed by a graphite ball on a soft iron handle. The ball can be raised by means of the electro-magnet shown in the diagram.

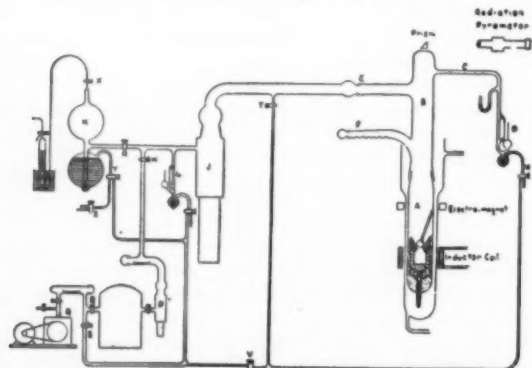


Fig. 5.—Apparatus at N.P.L. for vacuum fusion method of determining oxygen, hydrogen and nitrogen in metals.

* See, e.g., *Metal Progress*, April, 1952.

† The authors wish to make acknowledgment to the Director, National Physical Laboratory, for these details of the apparatus and procedure.

The samples to be tested are placed in the arm (F) from which they can be moved one at a time when required by a magnet. The gases given off from the test samples are removed by the 4-stage diffusion pump (J) and are collected in a Toepler pump (K).

In operation the empty graphite crucible is raised to a temperature of the order of $2,500^{\circ}\text{C}$. and maintained at that temperature for approximately three hours. During this time any gases given off are pumped to waste through the mercury diffusion pump (P) and finally through the rotary pump (Q).

At the end of this time the gases given off are negligible and the system is working under a vacuum of the order of 10^{-6} mm. of mercury. The temperature of the crucible is then allowed to fall to about $1,600^{\circ}\text{C}$. if the samples are steel and to a corresponding temperature for other metals. The ball is raised, a sample moved from the arm (F) and allowed to fall into the crucible where it melts, the gases it contains are drawn off, collected and analysed. During this time the graphite ball is allowed to close the mouth of the crucible to prevent molten metal being emitted but the gases are allowed to escape by grooves in the base of the ball.

Hot Pressing of Metal Powders

Several very successful installations are at work in Britain for the manufacture of hard carbide parts such as cutting tools and dies, etc. In all cases the technique is the same, that is, the hard carbide powder is placed in an accurately machined graphite mould, and the mould is heated by induction. Simultaneously, pressure is applied to the powder in the mould. The size of the parts made in this way varies from a fraction of an inch to 20 in. or more diameter. In an installation for the manufacture of tungsten carbide die rings, four furnaces, each mounted on a bogie truck, are available for heating moulds for the manufacture of die rings ranging from 5 to 22 in. diameter. The illustration shows the largest furnace, which is rated at 100 kW, 800 V, 3,000 c/s in the working position within the hydraulic press. The motor alternator and its auxiliary equipment is located in a sub-station behind the press, and the control panel is built into the wall of this sub-station. In another installation, several small parts are produced simultaneously in one mould, and the total process time in such a case is a few minutes only, whereas the process time for one large ring on the press equipment is approximately 1 hour. This particular process is an example of a technique in which induction heating is essential, as any other heating method is almost impracticable. Nevertheless the heating costs by induction are low, because the electrical efficiency of induction heating a graphite load is very high, usually over 80%.

Economics

The reasons for introducing high frequency heating as an industrial process, replacing other forms of heating, are well-known and have been stated many times. It may be to make things better, more cheaply or more quickly, or to improve the working conditions of the operator. All these ends, of course, are in a sense economic, in that in the long run they will be a financial asset to the firm employing the high frequency plant.

From the examples of applications already given, it may be seen that, *properly applied* (and this generally involves mechanisation), H.F. induction heating can show considerable direct savings when used to replace

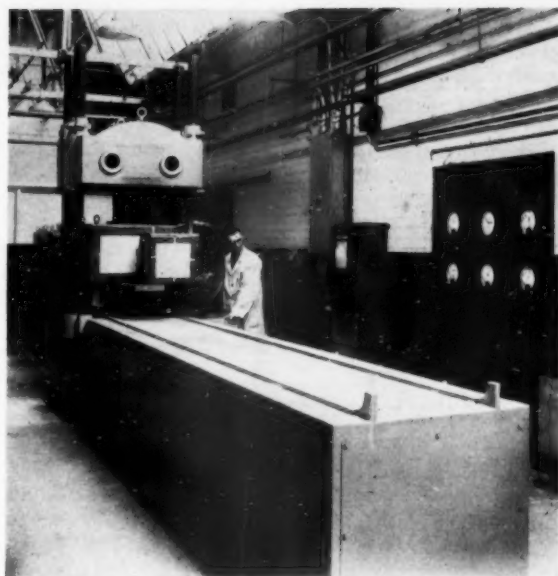


Fig. 6. — 100 kW 3 kc/s equipment and hydraulic press for hot-pressing of hard carbides.

older methods of heating, as for example in heat treatment and heating for forging. In many instances, H.F. heating also yields indirect savings because of the improved working conditions. In general, it may be said that where a heating operation is required for large numbers of similar mass produced parts, H.F. heating should be given careful consideration. Yet again, in some heating processes the induction method may be the only practicable one, as for example in some vacuum heating and melting techniques, some metal powder hot-pressing processes, and in the surface-hardening of light engineering components made in medium carbon steel.

Referring particularly to heat treatment, the H.F. method is well suited where localised heating is required. On the other hand, it is not particularly suitable where a constant temperature is to be maintained for a relatively long time, nor where irregular shapes are involved.

Correspondence

PRESENTING A TECHNICAL PAPER

The Editor, METALLURGIA.

Sir,

Mr. Willcocks gives a lot of good advice on "Presenting a Technical Paper,"* but I do hope he does not suggest that an author should ever read his paper. Even if a paper will not be published, I think a young author would always be well advised to write it out in full, but if he reads it word for word three-quarters of the audience will be bored stiff. If one knows one's subject it is quite easy to talk for an hour from notes covering not more than one sheet of foolscap.

Yours faithfully,

J. Ferdinand Kayser,
Gillette Industries, Ltd.

* Metallurgia, 1954, March, 122-123.

Problems and Procedures in Proving Die Casting Dies

By W. M. Halliday

Before regular production can commence in the foundry, new die casting dies must be proved, to ensure that they will produce castings of the required quality, and that they are operating satisfactorily. The importance of careful proving is stressed by the author, and details are given of checks to be made at this stage.

INTELLIGENT component and die design, coupled with precision construction and careful use of the die, are prime essentials for the successful development and completion of any new die casting project. Before regular production commences, however, the die must be proved, and at this stage a number of problems may arise which must be solved if maximum efficiency and trouble-free production are to be attained.

With every new die casting job a number of somewhat indeterminate factors usually obtrude to exert some influence on the shapes, forms and sizes permissible in the component; on the design and construction of the die; or on the character of the working conditions attending its use.

The magnitude and full practical effects of these factors cannot always be foreseen when designing the die, or during its manufacture. Often they are only revealed when the new die has been completed and put through its trials before being put into full production use. This applies regardless of whether the component and die designs are simple or complex, for the reason that every individual die cast article possesses at least a few—and often many—“unique” characteristics, whose reproduction entails corresponding “uniqueness” in the design, construction or operation of the die.

Furthermore, practically every new die requires some adjustment before satisfactory castings can be produced. For instance, the individual items of the feeding system—runners, gates and sprues—have to be carefully checked for capacity, correct location and their influence upon the direction of flow, rapidity of filling the cavity, and ability to induce sound clean castings.

Sometimes alterations to the sizes of the cavity forms, cores, or similar elements in the die are necessary to bring critical sizes on finished castings within the customer's tolerances. Adjustments may also be required in respect of the finish of cores, cavity walls, ejectors and like parts, to ensure that the die operates in the smoothest and speediest way, allowing castings to be ejected expeditiously yet safely, and with good surface finish. Slight errors in tool-making, discrepancies in the blending or matching of movable members, and the correct working of die mechanisms, etc., also call for corrective attention at the proving stage.

Die casting dies, for both gravity and pressure processes, usually have to operate under extremely onerous conditions, i.e., at elevated temperatures (with alternate heating and cooling), at high pressure, and at high-speed, etc. These are often inimical to accuracy, good surface finish, and high quality in the castings, and to long life of the die. In extreme cases the effects

of such difficult working conditions may lead to a serious reduction in the effective working life of the die, and to considerable maintenance work.

The solution of these and kindred problems calls for all new dies to be carefully tested, tuned, and proved, so that they may be properly adapted to the working conditions, and to the production of good castings. The efficient execution of proving tests demands tool-making skill and practical experience in die and alloy behaviour. Unless these proving operations are conducted skilfully, according to some well planned scheme, considerable difficulties, delays and irritation may occur on the foundry floor.

An ill-adapted new die is a source of continual trouble, worry and expense when put into production, as castings produced therefrom may fail to meet the customer's requirements with regard to accuracy, strength, appearance, durability, and so on. Production may be quite uneconomical, and an unduly large proportion of castings may be defective. Such a poorly-adapted die may also prove costly to operate, owing to the greater amount of maintenance attention required.

Proving in Large and Small Foundries

The importance of properly organised proving procedures and tests to cover the foregoing factors is recognised in many large die casting foundries. Often, a separate pilot or proving department is established for carrying out these tests on all new dies before their issue to the production casting shop.

Dies are made to function correctly and efficiently in every mechanical requirement, and sample castings are produced to the necessary standards for submission to the client. These conform to the customer's requirements as to accuracy, soundness, durability, appearance, etc. Proper casting sequences are worked out, covering all working conditions, and discrepancies in new tools liable to cause inaccuracies in the finished castings, or impaired working life of the dies, are discovered and eliminated at this stage. In this way, later production is made as fool-proof as possible.

This method is of the greatest practical value, because of the satisfaction thereby ensured to customer and die caster, and the simplification of the subsequent normal production usage of the die. Frequently, such proving tests may be protracted and difficult, and must be conducted with care. cursory proving, as a result of lack of time to make all necessary diagnoses and corrections, is always unsatisfactory, and is likely to be a source of subsequent trouble with die or castings, or both.

Resort to such a separate special proving department is, however, only practicable in the large foundry having ample financial and plant resources, and where a considerable number of new dies is regularly being made. In the smaller foundry, where new productions call for the proving of relatively few new dies, a different method is needed to avoid the heavy outlay involved in allocating special die casting equipment and personnel for such purpose.

In the small die casting foundries, proving tests generally have to be judiciously telescoped into the ordinary day-to-day production. When a newly constructed die is ready to undergo proving tests, it is mounted on a die casting machine engaged in regular production service, as and when conditions allow. Thus, normal casting activities may have to be interrupted frequently, and in some cases considerably delayed. Under these circumstances, proving operations are liable to be ill-planned, sporadically applied, unduly hurried in their performance, and, most frequently of all, very unsatisfactory in their practical results.

Time is always the most pressing factor, and a die has to be mounted on the die casting machine for the shortest possible period, so the latter may revert to its normal production with the least delay. The tendency is to instal the die on such a machine for just sufficient time to produce a few sample castings. These may not meet satisfactorily every requirement of the customer, but may be adjudged of reasonable quality or accuracy for despatch to him for approval purposes. Generally, such known inferior samples are accompanied by a more or less apologetic explanation of the known imperfections, etc., and a claim that they will certainly be eliminated later when bulk production commences, or when the die has settled down. Reservations and promises of this character are extensively made in respect of surface finish, precision dimensions, cleanliness, location or magnitude of flashings and similar points.

If the causes of any such imperfections, etc., have been elicited properly during the hurriedly-conducted proving operations, the promised improvements may be attained quite easily and early when full-scale production is started. On the other hand, if their underlying causes have not been thoroughly investigated, and efficient remedies have not been evolved and applied at the initial proving stage, it may well be that a large number of inferior castings will be passed to the customer before satisfactory rectification is achieved.

Quite apart from these serious objections—which of course never help towards building up harmonious and co-operative relations between die caster and customer—failure to eliminate imperfections at the proving stage may lead to delay, trouble, irritation and added expense when later production operations have to undergo a major interruption to introduce necessary corrections.

Points to be Checked

Some of the chief problems to be overcome at the proving stage will be referred to in the following pages, not only to serve as a guide to designers and toolmakers as to the need for comprehensive tests conducted in an organised and systematic manner, but also to illustrate the numerous practical advantages for both customer and die caster to be derived from the adoption of an improved testing procedure of the character outlined.

Setting-up the Die

First of all, a new die must be properly mounted on

the machine platens. It is surprising how frequently investigations into the causes of some die casting trouble or other show it to be due to inaccuracy or insecurity in the setting-up of the die halves on the machine members.

It is essential for such halves to be in true alignment, irrespective of the correcting influence exerted by the main dowels in the die. Such dowels are quite effective, of course, for correcting slight misalignments, i.e., of the order of 0.003 in. off-set, but if die halves are improperly fixed on platens so as to be out of line a greater amount than this, damage or permanent distortion of the dowels may result. This is not the only trouble liable to arise from such cause. For example, the die halves may be prevented from sealing closely at all points over their parting-joint, thus allowing serious leakage of molten alloy and the formation of thick flash on the castings. Again, the internal mechanism of the die, covering such items as cores, core-slides, ejector-rods, gearing and so on, may be made very stiff to operate. The ejection of the component may be drastically hindered as a result of such misalignments and stiffened operation of die parts.

The sprue channel in the rear (stationary) die-half must be axially in line with the entry channel in the fixed platen. With certain types of machine, the rear die-half has to be provided with a seating around the sprue channel, for matching the hemi-spherical nozzle of the pump mechanism through which the alloy charge is injected. Such seating must seal properly on the nozzle to avoid leakage of alloy at each injection shot.

These points can only be properly determined by making actual tests with die and machine.

Die Operation

Next the die mechanism must be very carefully tested for smooth, accurate operation when the die has been heated to the normal working temperature. Core-plugs, slides, ejectors, gears, cams or similar parts of the die mechanism may function extremely well when the die is cold, but totally different conditions prevail when the tool is heated to the casting temperature. Movable parts may then function stiffly, or even seize-up in their bearings, due to the effects of normal or unequalled expansion and contraction of the die members. This is likely to arise particularly with dies used for the high melting-point alloys, or when the cavity forms and layout are of such a character as to make it difficult to maintain good thermal balance throughout the die. As a result of such stiffened working, delicately fashioned cores, slender ejector-rods and similar parts may suffer injury from distortion or fracture due to overloading. The means of lubricating all such movable die elements must also be checked after the die has been heated to the normal working temperature. High working temperatures make adequate and sustained lubrication difficult, and special lubricants or oiling facilities may be required.

Undesirable features of this nature, arising from the heating of the die, must always be ascertained and corrected before the new die can be put into regular production service.

The Metal Feed

Every new die casting die must be adjusted in respect of the alloy feed to the cavities. This mainly concerns the necessary adaptations to the runner and gate channels. The latter, in particular, may require enlargement,

modification in shape, or even entirely re-orientating to obtain the most effective and rapid cavity filling. Alterations to gate and runner capacities, shapes and locations may also be necessary to avoid porosity in die cast walls by eliminating trapped-air pockets, or by avoiding incomplete filling of the cavity. In the same way, adjustments may be required to the alloy feeding provisions in the die, to ensure superior surface finish and cleanliness, and freedom from several other common irregularities, such as flow-marks, flash, shrinkage porosity, etc.

Castings Accuracy

Alterations of some kind may be required in respect of cavity shape and dimensions, or to the sizes of cores, in order that dimensions on the finished castings may be held to the required close tolerances specified by the customer. In the case of precision castings, fine accuracy is often difficult to attain and calls for close attention. Checking and repeated alteration to the die, may be necessary because many factors have to be balanced, notably those of the expansion of the die when heated, the contraction of the solidifying casting in the die, the restraining effects induced by the presence of cores, the rapidity with which ejection may be accomplished after injecting the alloy charge, and the form of ejection employed.

Often adjustments are required on cavity shapes and sizes to ensure correctness of shape on finished parts, or to provide a greater degree of ejection draft in the cavity or upon cores, so as to simplify the extraction of the casting. Furthermore, tooling marks, slight undercuts, bad jointing, inferior surface polish, rough patches and similar surface defects in the die cavity and cores need to be removed to eliminate sticking or hanging of castings during the ejection stage.

Most of the above points can only be discerned as a result of practical tests, often prolonged ones, made with the new die. Failure to eliminate them effectively at the proving stage may lead to slower working of the die and/or the development of numerous minor faults and inaccuracies on finished castings.

Ejection Features

Coupled with the foregoing requirements, the new die must always be thoroughly checked with regard to the ejection features. This means determining whether a sufficient number of ejector-rods is employed, and whether the rods are located in the best positions on the castings to ensure that the component is ejected without delay, damage or distortion.

In cases where ejection is accomplished by stripping sliding cores from a hollow casting, these members must be carefully checked in respect of the timing of their withdrawal, and to ensure they are pulled out in a uniform manner to avoid distorting or cracking the walls of the casting.

Surface Finish and Appearance

Invariably castings taken from a new die have to be proved for adherence to stipulated standards of surface finish, cleanliness, smoothness and appearance. This is always difficult, because some time must necessarily elapse before all working conditions are stabilised and the requisite adjustments made. Moreover, with any new die, anything up to 500 "shots" have to be made before the cavity walls become coated evenly with the

natural oxide film, giving the characteristic egg-shell or matt finish to castings.

The development of satisfactory surface finish may involve the elimination of numerous flash lines in the die or their modification to enable resultant flash fins on the component to be trimmed in the most economical and clean manner.

Castings may also have to be proved for matching or fitting with other components. This may involve very careful checking in respect of machining allowances and variations on critical dimensions. On the other hand, parts may have to be checked to ensure their ability to take electroplated finishes, chemical dips, or other decorative, utilitarian or protective treatments.

Elimination of Faults in Castings

Die actuation and general operating conditions may have to be carefully adapted to eliminate the onset of the several weakening faults to which die castings are prone. This, too, may incur some modification to runners, gates, cores, ejectors, air vents, water-cooling provisions, cavity formations, insert-retaining or locating features, and so forth.

It is also very important to determine, by practical tests, the best sequence and timing for all die movements. This relates particularly to the operation of movable cores in complex dies, where such members have to interlock or be positively related in a certain manner. This is especially so with new dies having numerous movable or collapsible cores disposed to operate in different planes, but which must be correctly inter-related throughout their movements.

Speed of Die Operation

A new die has to be proved as to its ability to be worked consistently at the specific speed estimated by the designer, for pricing castings to customer. Determination of efficient working speeds and best output at the very outset of the regular production run is of the utmost importance in the small die casting foundry, to safeguard against loss and inefficiency.

Miscellaneous

Efficient proving tests involving all-out operation of a new die over a sufficiently long trial period can elicit much other valuable practical information concerning the behaviour, idiosyncrasies and durability of the die and its reactions to molten alloys, elevated temperatures, high pressures, etc.

Such comprehensive tests often reveal the need for subsequent trimming, machining and inspection procedures, and the most suitable and economical means of carrying out these procedures may be suggested by examination of actual castings. Similarly, the best type of tools for the die casting machine operator are indicated. These may be required to facilitate the actuation of manually-operated cores or core slides; as ejection aids; or to provide additional locking provisions for certain die elements. The design and mode of operation of such tools are very important, and should be determined as early as possible. The provision of properly designed tools for such purposes is the best means of avoiding later damage to die members or castings, and may simplify all essential hand operations with the tool during each cycle of operations.

This information is of the greatest help to the die designer and toolmaker. For example, areas subjected to the greatest stress or loading are ascertained; points where abrasion or wear are most prone to occur are revealed and the effects of unequalled heating or pressure are demonstrated. Such knowledge indicates the effective remedial treatments to be adopted to safeguard working or promote longer die life.

Careful proving tests and tuning-up on new dies can also provide useful guidance as to inherent drawbacks in the design or construction of the tool; weaknesses in die materials; and the value of protective treatments applied to die materials, etc.

During proving tests, also, the need for effectively safeguarding the die mechanism by introducing fool-proofing devices, or better methods, can be foreseen. This is extremely important in ensuring maximum safety for both operator and die mechanism. Introduction of safeguarding devices may circumvent possible damage or deterioration of the die due to ill-use or inadvertent incorrect operation. Often the die designer is unable to envisage such safety requirements at the drawing-board stage.

If, after viewing sample castings, the customer should require substantial modifications to the shape, sizes or other features of the castings, the necessary alterations to the die are usually more easily and economically introduced during the proving stage than later, when the tool has been completed in every detail, including hardening and final polishing.

Sometimes, the sample castings supplied to the customer at the outset do not meet working requirements in respect of strength or rigidity. To overcome such drawbacks may entail increasing the wall thickness, or introducing ribs, beadings, flutes and similar simple strengthening features. Strengthening formations of this character can be readily and economically introduced during the proving stage, before such critical portions of the die have been hardened.

Inserts

Another important requirement which can often be satisfactorily cleared up at the proving stage relates to the feeding, locating and retaining of metallic inserts in the die cavity. Cast-in insert pieces may have to be mounted within the die cavity in a "difficult" or unusual manner. Performing such operations manually may prove exceedingly slow, and be attended with some risk of injury to the operator, but often it is possible to arrange an automatic or semi-automatic form of feed for such parts.

Inserts must always be securely anchored and accurately located in the cavity site, and the best means for accomplishing this are generally revealed as a result of careful working of the finished die, and observing all the conditions at work.

Fastening Devices

Die cast components are often assembled and affixed to mating articles which may or may not be die cast. Because some die casting alloys have reasonable malleable properties, it is often feasible and economical to cast-on integral rivets, pins, studs, bosses, lugs or similar features for simplifying later fastening requirements. The need for such cast-in fastening devices, and the way in which they may be most economically introduced into a casting, are often not presented until the die has been

completed and subjected to certain proving tests, with the provision of castings for actual assembly tests.

Value of Proving

The foregoing are some of the more important features to be determined during the proving of any new die casting die. The more complex the construction, the more essential it is to determine accurately these features. Furthermore, in the case of dies to be used with the high melting-point alloys, such as aluminium-bronze, the copper-base alloys, or magnesium, additional problems may be encountered, making the determination of such features still more necessary before actual bulk production begins.

The effective proving of a new die, however simple its construction may be, cannot be reliably accomplished by making only a very small number of castings. Many factors with die casting only manifest themselves with any degree of uniformity after not less than 100 castings have been satisfactorily produced from a more or less continuous run, and when certain other factors have been stabilised.

At the end of such an adequate proving operation and prolonged test runs, it should be possible for the die-caster to be assured of the following points.

- (a) That the castings uniformly conform with the precision tolerances on critical dimensions; are structurally sound; have good surface finish and are relatively free from irregularities or from thick flash or other surface blemish.
- (b) That the castings can be produced economically.
- (c) That the most satisfactory temperatures and other conditions for alloy and die have been determined.
- (d) That injection and die-clamping pressures have been regulated to prevent leakages from the die parting-joint.
- (e) That the velocity of the molten alloy stream entering the cavity is of a scale to give the best cavity fill and expulsion of air from recesses or pockets in the cavity.
- (f) That air-venting needs have been properly determined and adequate provisions introduced into the die.
- (g) That a reliable thermal balance has been obtained in the die by water-cooling or other customary means.
- (h) That the best operational speeds and procedures have been worked out in practical manner for the die.
- (i) That cores or cavity walls, etc., have been corrected in respect of draft or smoothness of surface finish, so that ejection of the castings will be rapid, simple and safe.
- (j) That die mechanisms are successfully safeguarded against accidental manual or mechanical misuse.
- (k) That all mechanical features of the die have been thoroughly tested and made satisfactory, so the tool is well fitted for starting bulk production service, pending completion of certain minor hardening or further polishing of a few die members.

Being assured of these points, the die caster knows that actual production may be commenced without

delay, since no serious form of trouble is likely to be encountered at that stage.

It is essential, for several reasons, to make written records of problems arising during die proving together with full details of all solutions applied, and any other interesting information or new experience gained. These results, if permanently recorded, are available for the future guidance of both die designer and toolmaker, to assist in overcoming difficulties arising with other new dies.

Records of this kind also permit a much more reliable costing to be maintained of die construction and proving requirements. The latter—in the small foundry—are often hidden among the larger manufacturing or maintenance costs, and thus are not generally known with exactitude.

If such recorded information about proving operations, etc., is employed in conjunction with written records covering later die-maintenance requirements valuable information may be obtained regarding the tendency of certain recurring faults, weaknesses or irregularities to develop with a die or casting. This, in turn, will assist in determining the most economical yet effective corrective treatments to be applied.

Checking Equipment

Economical and efficient proving operations can often be considerably simplified by the use of well planned accessories or ancillary equipment of an inexpensive kind. For instance, proving tests conducted on the die casting machine may be very materially simplified and shortened if the new die is first set-up on an ordinary bench-type fly-press. This is adapted, by means of a simple fixture, to hold the respective die halves, allowing them to be opened or closed at will, under the requisite pressure. In this way, certain important movements, alignments or features of the die mechanism may be checked without mounting the tool on the die casting machine at all.

The ability to hold die halves rigidly to the press-ram and platen, in a strict relationship, coupled with the considerable pressure available, enables die halves and the die mechanism to be checked in important respects in a manner wholly impracticable when the die is loosely resting on a work-bench, and the halves have to be manually prised apart with bars inserted between the main parting-joint surfaces. This common practice is a frequent source of considerable damage to die parting surfaces, etc.

Mounted upon such an adapted fly-press, the accuracy or uniformity of seal obtaining over the entire main parting-joint may be reliably and quickly tested. This is accomplished under almost the same conditions as when the die is mounted upon the platens of the die casting machine itself.

The ability to open and close die halves under proper mechanical guidance and pressure in such a fly-press also permits the smooth fitting or working of dowels, cores, core-slides, ejector-rods, and all similar movable elements to be tested in equally simple fashion, just as if the die were mounted upon the die casting machine.

By using an adapted fixture for the fly-press, innumerable important mechanical features may be checked on the new die, and corrected or adjusted as required without having to mount the tool on the die casting machine. As a result, the latter may be retained on normal continuous production work with far less interruption.

Use of Standard Die Parts

Die proving needs may also be considerably simplified and expedited by using standard forms and sizes for certain die elements. The value of this is frequently overlooked in the small works, yet in the interests of possible greater economy it amply repays careful attention along the following lines.

With almost every kind of die there are some common elements, which, with little trouble but much advantage, can be standardised to be applicable for use with dies of different sizes or types. For example, die halves are normally aligned by dowels or guide pins. Two or three sizes of dowel, all of the same standard (headed) form, etc., usually suffice for use with dies of considerably different size. The same applies to the method of fixing dowels. In practice, many methods are employed for securing dowels in place in a die block, but economy in manufacture, setting and replacement during working service is achieved where the fixing method is standard for every size and kind of tool. The spacing of dowels in the die halves is another important point offering excellent possibilities for standardisation.

In the case of die blocks, it is usually possible to adopt a considerable measure of standardisation in respect of their external shape, i.e., whether rectangular or square, and of the overall dimensions. Where these features are standardised and made interchangeable within a very small range of shapes and sizes, machining by jigs is simplified. The same considerations apply to the sprue channel size and taper. This is usually bored in the stationary die half or in a separate sprue bushing mounted in that die half, to the highest quality in respect of finish, taper and accuracy. By standardising the design and fixing of such sprue bushing, or the size and taper of the sprue channel, efficient reamers and inspection gauges may be employed to simplify production and to ensure that the best results are attained.

Fixing bolts or straps employed for fastening die halves to the machine platens should be of a standard type and size, as far as practicable. Ejector-rods should similarly be of a standard pattern and stocked in a range of a few different sizes, while pillar guides, controlling the sliding movements of the ejector-rail, may also be easily standardised to a common design, a few sizes, and the same simple method of fixing.

Correction

WE regret that a discrepancy appeared in an article on "Faults in Pressure Die Castings," which was published in the February, 1954, issue of *METALLURGIA*. In the section on rough patches it was stated that: "The patch may be extensive or very limited in area, being very slightly raised above the surface of the casting." In a later paragraph one of the causes was given as "some accumulation built-up on the cavity surface." Rough patches due to such a cause would, of course, take the form of an impression in the casting, not a raised area.

HEENAN AND FROUDE, LTD., of Worcester have received an order from the Bristol Aeroplane Co., Ltd., for a special high-speed Froude dynamometer, for research work on gas turbines. This dynamometer will be rated to absorb 1,000 b.h.p. at speeds up to 12,000 r.p.m. and will achieve new standards in accuracy and sensitivity of readings.

Metals and Marine Engineering

Institute of Metals Presidential Address

In surveying, in his Presidential Address to the Institute of Metals, the application of non-ferrous metals in marine engineering, Dr. S. F. Dorey, C.B.E., F.R.S., Chief Engineer Surveyor, Lloyd's Register of Shipping outlined the outstanding developments in the field since the formation of the Institute in 1908, before proceeding to a discussion of the important part non-ferrous metals had played in this progress. An abridged account of Dr. Dorey's address is presented here.

MANY important developments have taken place in the marine engineering field since the foundation of the Institute in 1908. Steam conditions have increased from pressures and temperatures of 240 lb./sq. in. and 400° F. to 625 lb./sq. in. and 950° F., respectively. Associated with this progress there have been the change over from coal to oil fuel and the displacement of the steam engine by the steam turbine and the oil engine, whilst more recently the gas turbine has been applied as a marine prime mover. In 1908 oxy-acetylene welding was used for certain limited hull, boiler and machinery repairs and the extensive use of fusion welding in engine and boiler shops and in shipyards for constructional purposes at the present time appears remarkable in comparison with these early practices. These and other developments have been allied with corresponding progress in the metallurgical industries which have provided the essential materials of construction and developed improved methods of fabrication. The non-ferrous metals serve a vital role in ensuring efficient operation and adequate service life of machinery and structures, although the proportion employed in relation to other materials may be relatively small. Since manufacturing and operating conditions create the demand for existing and improved alloys, this survey of the use of non-ferrous metals in engineering will be based on the influence of the aforementioned conditions.

Corrosion

The corrosive nature of marine environments constitutes one of the most arduous service conditions metals are required to withstand. The marine engineer has derived great benefit from the work on the corrosion problems associated with marine condensers carried out originally by the Institute's Corrosion Committee (founded in 1910), and since 1930 by the B.N.F.M.R.A. The benefits conferred by additions of up to 0.05% arsenic in minimising dezincification of α -brasses and aluminium brasses are now well established, and good progress has been made in the development of alloys to withstand impingement attack or corrosion-erosion, in which high local liquid velocities, associated with air bubbles exceeding a critical size, produce a scouring action capable of removing protective scales and deposits and, thereby, accelerating corrosion. Copper is now confined to less arduous conditions in water systems, but arsenical 70:30 brass is still used for condensers with liquid velocities below 7 ft./sec. For more severe conditions tubes of 70:30 cupro-nickel with 0.4-1.0% iron and 0.5-1.5% manganese or arsenical 76:22:2 aluminium brass are used.

Marked improvement in resistance to attack in stagnant and flowing water was obtained by adding

1-2% iron to cupro-nickels with 5-10% nickel. Tin-bearing copper alloys with tin contents below 8% have proved inferior to these alloys, but with 12% tin good resistance to erosion has been observed. Metallic coatings applied to the tube surface have not been considered worthy of continued use, but attention is being directed to the use of duplex tubes for certain applications, such as chemical and refrigeration plants.

Although the improved alloys are suitable for normal marine conditions, operation involving polluted cooling waters still presents an important problem, as does the associated bio-fouling caused by marine growths. In addition to causing pitting by its own action, the growth tends to trap decaying debris, thereby increasing the attack on the metal surface.

The use of dissimilar metals, whether in contact or in different parts of a continuous system in contact with sea water, inevitably leads to cathodic corrosion, and metals and alloys of widely differing potentials in sea water should be avoided. Steel-to-aluminium jointing is becoming increasingly frequent, and corrosion of the aluminium due to local contact is usually avoided by interposing galvanised strip, or non-metallic packing, and bolting with surface-protected steel bolts and the application of zinc chromate paint. Steel riveting of aluminium structures exposed to marine atmospheres is, therefore, undesirable.

Copper and nickel alloys are avoided in contact with aluminium and its alloys, and the effects of copper-to-steel contacts are minimised by zinc coating the steel surfaces or by the use of protection blocks which corrode sacrificially. Although widely used, doubt has been cast on the value of zinc as a sacrificial protector, because of the ineffective bonding of zinc to steel and the semi-imperious layer of corrosion product formed on the zinc surface. Addition of 0.5% lithium to the zinc has been suggested as a means of obtaining a less-insulating corrosion product.

Iron and steel affords protection to copper alloys, but nickel-base alloys, being more noble, are generally confined to applications with stainless steels, or where the sections are such that some degree of corrosion may be tolerated.

In recent years, the economic and practical value of cathodic protection of buried pipelines and structures has offered an alternative means of minimising corrosion. High purity magnesium anodes have proved most effective and, in conjunction with suitable impressed potentials and current densities, have been extended in use to protect marine pipelines, structures and the submerged surfaces of ships laid up in reserve. Whilst such refinements might prove effective in extensive docking periods for operational warships, the benefits afforded to

merchantmen are doubtful, as these vessels are docked at frequent intervals for many purposes.

In tankers carrying alternately oil cargo and sea-water ballast in the same tanks, flat surfaces and other regions which do not drain efficiently undergo rapid corrosion. The high oxygen content of the oils is mainly responsible, although the sulphur content may be a contributory factor. Steaming out of the tanks aggravates these conditions by loosening adherent scale and increasing the chlorine-ion concentration at the higher temperatures involved. Although cathodic protection has been used, controversy exists as to the advantages obtained. It has been suggested that aluminium alloys—as spray coatings, linings or tank units—might be satisfactory.

A further aspect of the construction of water-carrying systems which needs to be considered is the use of dissimilar metals, as the deposition of minute quantities of one metal from solution on to another of more anodic characteristics has been observed to accelerate corrosion failure.

Solutions to the corrosion problems arising in marine engineering offered by surface coatings, wastage blocks, or impressed cathodic protection cannot always be employed, or are not entirely efficient. An effective solution appears to be far from obvious, and the engineer can only hope that the metallurgist, in his researches, may develop more efficient methods of passivation.

Cavitation Erosion

Under suction conditions of dynamic fluid flow, the surfaces of propellers, impellers and similar hydraulic machinery components may suffer severe surface damage by cavitation erosion. The collapse of cavities formed on these surfaces is considered to release quantities of energy in the form of localised forces, similar in nature to water hammer. These forces may bend propeller blades, but they usually produce local surface rupture with severe distortion of the crystal structure. The situation is aggravated by the increased local turbulence resulting from the local damage. Controversy exists as to the part played by corrosion. Cast iron and cast steel are prone to have local regions of porosity which are easily eroded and give rise to a deeply pitted form of attack. Bronzes exhibit eroded regions having the appearance of areas that have been subjected to intense local sand-blasting, but, despite their more resistant nature, bronze propellers have been known to decrease in weight during service by as much as 10%, attributable to overall corrosion and erosion losses. In consequence of such losses, the one-node mode of torsional vibration of the machinery dynamic system may be raised, and critical vibrations brought in close proximity to service speeds.

A reasonable assessment of the erosion-resistance of an alloy is given by the product of the surface Brinell hardness number and the corrosion-fatigue resistance expressed in tons/sq. in. for 50 million cycles of reverse bending. The more highly resistant alloys have values in excess of 800, and in descending order of merit they include austenitic stainless steels, aluminium bronzes, with or without nickel additions, low-nickel stainless steels, silicon Monel, Monel metal, high-tensile bronze, and Turbadium bronze. Below 800, the normal manganese bronzes, silicon bronzes, phosphor bronzes, gun-metals, cast irons, and aluminium alloys are placed. This does not imply that the manganese bronzes which have given such good service have

poor resistance, but they are used purely as a basis of comparison. Of the alloys showing cavitation-erosion characteristics superior to those generally used, the stainless steels and aluminium bronzes appear the most suitable for manufacture and service purposes.

Cast iron, which is still widely used as a propeller material, should have its surface skin intact, as this increases its resistance to erosion, as do additions of copper, nickel, and chromium. Soft alloy "stopper" metals employed to plug local casting defects are of negligible value.

Nickel deposits, applied to the surfaces of cast-iron propellers of trawlers, have provided increased corrosion and erosion-resistance in service. The severe corrosion, which occurred at fractured sections, and the high cost of the deposit caused this practice to be abandoned, however. Similar deposits applied to bronze propellers have also proved uneconomical. Spray coatings of zinc, lead and aluminium have been applied to cast-iron propellers in service: pure aluminium was found to be the most reliable, although respraying of exposed areas became necessary at intervals.

It has been shown that the addition of aluminium, nickel, or both, to copper- or copper-zinc-base metal, resulted in alloys having low cavitation-erosion-loss characteristics. The latest materials used for large marine propellers are copper aluminium alloys with nickel and iron additions (resembling B.S.1400 A.B.2), and the more recent copper alloy with high aluminium and manganese.

Impellers of pumps are invariably of gun-metal, manganese bronze, aluminium bronze, Monel metal, or stainless steel, the last three being generally employed where the conditions are most severe in respect of temperature, stress, and erosion.

The exceedingly low erosion-resistance of aluminium alloys cannot be neglected if these materials are to be used for hull construction and for small-sized propeller castings, and alternative materials may have to be used for hull sections that experience cavitation.

Sprayed metal deposits applied for the protection or reclamation of surfaces experiencing cavitation erosion have been found to be of only temporary value: sound fusion welds represent the best method of repair and surfacing.

Fatigue

Alternating stresses, arising from the excitation of natural modes of vibration of machinery and component mass-elastic dynamic systems, have resulted in many service failures. Mathematical analysis in conjunction with dynamic stress measurements, obtained during operation of machinery installations, has led to a reduction in failures of this type, either by the avoidance of critical vibrations in the vicinity of operating speeds, or by limiting vibration stresses to values below the fatigue strength of the materials employed.

Alloys having enhanced fatigue strength are advantageous where these conditions are involved, as shown by the radical reduction in failures of lead cable sheathing, subjected to vibratory conditions in service, by improving the poor fatigue characteristics of pure lead with small alloying additions of tin, antimony and cadmium. Aluminium-sheathed cables, although of improved fatigue strength, are not used for marine purposes, the cathodic quality of lead being more favourable.

The low corrosion-fatigue strength of plain carbon and many low-alloy steels, confirmed by reverse-bending salt-spray tests of 50-100 million cycles duration, at less than 4,000 lb./sq. in., has been responsible for machinery failures. Copper- and nickel-base alloys, in particular offer excellent corrosion-fatigue characteristics, and manganese, aluminium, and phosphor bronzes, Monel metal, and K Monel metal have all been used in preference to these steels for many shafting applications, including screwshafts of limited size. In addition, these alloys are frequently preferred to the chromium stainless steel because of the tendency of this material to pitting, especially in the presence of graphite grease.

There is a lack of information concerning the influence on the corrosion-fatigue strength of non-ferrous metals of mean stress, stress concentration and combined-stress conditions. At elevated temperatures the influence of mean stress in relation to fatigue is of marked importance owing to the deformation due to creep. Whilst it appears that internal damping cannot be relied on to limit alternating stresses to values below the fatigue strength, in a similar application a material of superior damping characteristics might give longer service life.

Elevated Temperature Service

The advent of the gas turbine focused attention on the requirements of alloys for service at elevated temperatures, and the search continues for materials of greater heat and creep resistance. Apart from the Nimonic series, ferritic and austenitic steels have been used in this country, but more extensive use has been made in the U.S.A. of alloys containing a high proportion of cobalt. To a large extent, gas turbine alloys have been based on three primary metals, stiffened by precipitation-hardening with the aid of small additions of other elements. Typical examples are nickel-chromium-iron, nickel-cobalt-iron and—more recently considered in Canada—nickel-aluminium-molybdenum alloys. Attention is now being directed to alloys of metals with higher melting points, such as chromium titanium and molybdenum.

The search for high-temperature materials has tended to mask the desirability of determining the operational limits of many familiar alloys used at less-elevated temperatures. Information provided by short-time tests is undesirable, as doubts remain as to the degree of stability of structure and as to the reliability of stress assessment based on these findings, when applied to components of installations constructed for long-duration service. Tests of not less than 10,000 hours duration are essential on many of these alloys. Moreover, a knowledge of the scaling properties is also important, as shown by the failure of certain copper-base alloys in gas-turbine heat exchangers.

Stainless iron and nickel-chromium ferritic and austenitic steels are the most commonly used materials for steam-turbine blading, but non-ferrous materials—such as brass, S Monel and Nimonic 75—are widely used for gland purposes.

Metal-to-metal contact is not uncommon at elevated temperatures, and galling has frequently been encountered at steam valve faces and guides. All steels are susceptible to this form of surface rupture, and the use of Stellite surface deposits has proved the most feasible method of overcoming these difficulties. Similar deposits are widely used for I.C. engine exhaust valve faces, whilst oxy-acetylene-deposited 80:20 nickel-chromium

alloy is being increasingly used for the repair of Diesel-engine valves, providing high resistance to corrosion and cracking.

For piston heads of I.C. engines, cast iron is still preferred by many engineers. Its replacement in heavy oil engines by forged steel was mainly based on increased soundness and pressure-tightness, although the use of centri-spun 13% chromium cast steel is based partly on its superior heat resisting properties. Whilst 20% chromium steel is considered superior, it has not yet been tried. Aluminium deposits on cast iron heads have been applied to reduce the heat absorption characteristics, but opinion differs as to the value of such methods. For heavy slow-speed engines, light alloy piston heads have not been used, but established Y alloy and R.R. alloys have been widely employed in high speed engines.

Thermal stresses resulting from joints between metals of dissimilar thermal expansion, or from temperature gradients in a single material, can reach considerable values, and the factors controlling thermal shock and fatigue failure require greater attention if these are to be avoided in service. The joint application of aluminium and steel to ship construction has recently been receiving attention in relation to induced stresses.

Applications of Light Alloys

The extension of light alloys to ship construction has been based on long-term policy, and their application is increasing with design and practical experience. The advantages for the present use of lightweight construction have been summed up as

- (1) A reduction in topside weight which increases the stability of the vessel, offering advantages not only in new construction, but in reconversion work.
- (2) Greatly increased corrosion-resistance of aluminium alloys, particularly against the detrimental effects of petroleum and its products.
- (3) Greater flexibility in the design of vessels operating in conditions which impose limitations on draft, beam, and length.
- (4) Reduction in contamination of cargo and ease of cleansing refrigeration and other holds.
- (5) For naval vessels, the non-magnetic characteristics and weight-saving are important, the latter permitting increased armour and armament.
- (6) Greater flexibility in hull design, permitting increased speed with the same machinery power or less power for equivalent speeds.

Of these items, the first has been the most important in merchant ship construction, topside weight saving having been effected by using light alloys for masts, superstructure, davits, lifeboats and accommodation fittings. Apart from the S.S. *United States* with its 2,000 tons of light alloys, the quantities used for these purposes range up to 250 tons.

For structural purposes aluminium alloys with up to 5½% magnesium are considered most suitable. With this maximum magnesium content and small additions of manganese and chromium, the tendency for precipitation of the β phase has been obviated, and so has the stress-corrosion associated with the presence of this phase. Aluminium-4% magnesium alloys (N.P. 5/6) are used for plate manufacture, as they are more suitable for hot working than those of higher magnesium content. The mechanical properties are generally good and meet the maximum stress requirements of 17 tons/sq. in. with

comparative ease. Further, their good welding characteristics render alloys of this composition superior to those of the heat-treatable type of alloy. There is, therefore, a tendency for this material to be more widely used, and in America alloys of similar composition may in future be employed in preference to the existing 61S-T6 alloy.

Alloy N6* (5% magnesium) is used for rivets, as well as H10 (1.0% magnesium, 1% silicon), the latter having superior extrusion qualities to the former alloy and being, therefore, more favoured. However, it is usually employed in the heat-treated (WP) condition, as is the corresponding American alloy 61S-T4. These alloys do not work-harden to the same extent as N6, but age-harden to give higher proof stresses. Age-hardening of rivets after quenching can be prevented by adopting the aircraft industry's practice of refrigerated storage. Rivets are driven both hot and cold, pneumatic methods being used for N6 rivets of the order of $\frac{1}{2}$ in. dia. (cold) and $\frac{3}{4}$ in. dia. (hot). The heating of aluminium alloy rivets requires greater attention than is usual in steel-rivet practice. Light alloy rivets are worked in a temperature range of 400°–500° C., higher temperatures being most undesirable.

The high-strength, heat-treated duralumin and aluminium-magnesium-zinc types of alloy are not employed in marine construction owing to their inferior corrosion-resistance. In the clad condition these alloys are not economic propositions, although they have been employed in some German naval vessels.

Many small craft have been constructed entirely of light alloys, using normal and stressed-skin techniques. They provide means of gaining general experience of fabrication methods, as illustrated by the recent manufacture of a 72-ft. yacht of light alloy welded construction. For the aluminium alloys to be extensively used in ship construction, efficient welding techniques must be developed. The self-adjusting inert-arc method, as used in the fabrication of this yacht, at present provides the most suitable method of fusion welding. However, as yet this method is severely limited for general shipyard use by the degree of penetration obtained, the need to maintain a clean and corrosion-free filler wire, and the difficulties of maintaining an inert atmosphere during open-air welding. The high degree of reliability attained in the fusion welding of steels has, therefore, placed aluminium alloys at present in a less favourable position.

Ease of handling gives the light alloys great advantages for hatch covers, crankcase doors and similar applications, but apart from these and piston castings, light alloys are not extensively used in the engine room, as the savings in weight are not sufficiently vital. In consequence, the cast aluminium alloys containing silicon and magnesium find only limited scope in the machinery of merchant ships.

The ultimate tensile strength of aluminium alloys used in ship construction is still relatively low, 20 tons/sq. in. being an almost limiting value for normal plates and sections. It must, therefore, be appreciated that the development of alloys having superior strength while retaining the other desirable properties of existing alloys, remains an important consideration.

Bearing Metals

Advances in lubrication theory and practice have been responsible for the efficient operation of machinery by

limiting surface contact to a minimum. Load and velocity variations may still result in changes from film to boundary lubrication, and the short-time contacts between the metal surfaces are minimised in their effect by suitable selection of the mating materials. Non-ferrous metals which exhibit a low friction coefficient and a high resistance to local seizure, in relationship to journal materials, perform a most important function in this connection.

Whilst these qualities are of major importance, the bearing metal must also have adequate mechanical strength at the operating temperatures to withstand the applied bearing loads, and sufficient ductility to tolerate normal amounts of malalignment. In addition, the rate of wear undergone by shaft and bearing surfaces must be exceedingly low and the corrosion-resistance must be of a high order. A great deal is, therefore, required of a bearing metal, and it is not surprising that no ideal alloy exists and actual selection for particular service forms a compromise or an ingenious combination.

In practice, two main types of plain bearing are used, thin-and thick-shelled. For heavy engineering purposes, too where heavy loads, low speeds, and flexibility occur, thick-shelled bearings are used. In I.C. engine practice, when line boring is preferred, thick-shell practice is obviously involved. The shell thicknesses vary from 8–12 mm. at a journal diameter of 600 mm. to 2–4 mm. for small diameter shafts. Although thinner shells may appear to be more favourable for the larger bearing diameter, this has not been confirmed in practice; and war-time economy measures involving reduced shell thicknesses proved unsuccessful.

With marine engine shafting of plain carbon steel, with a Brinell hardness between 121 and 173 (more commonly the former), high-tin Babbitt metal is used, but difficulty is experienced in getting entirely effective union over the whole surface. Keying is still widely employed but it offers little improvement against fatigue failure. Higher-speed engines, with increased bearing loads, high oil temperatures, shaft journals of heat-treated steel with a Brinell hardness of 300, and line-bored bearings, employ thick-shelled lead bronze, usually tin-backed to steel.

In practice, failures of thick-shelled bearings are divided evenly between (a) wiping and running of the metals, and (b) cracking or breaking up of the surface. A high percentage of failures of type (a) are due to oil starvation arising from neglect. Cracking of bearing metals by fatigue is exceedingly common, and may be associated with high oil temperature or simply with the inability of the metal to resist the loading conditions. These failures are invariably associated with the bearing halves supporting the high loads in reciprocating machinery.

Alternative bearing metals having increased strength while retaining the other qualities of the high-tin Babbitt metals have not yet been produced and engineers must, therefore, contend with the failures as best they can. Whether the aluminium-20% tin alloys or the 30 : 30 : 40 copper-silver-lead alloy, exhibiting higher fatigue properties, will prove superior to either of those described in thick-shell applications has yet to be demonstrated.

More lightly loaded bearings for line shafting and similar purposes utilise lead-base Babbitt metals. These give excellent service, especially in view of the flexibility of marine-shafting installations and the variation in alignment with loading conditions of the ship.

* British Standard Classification

The realisation that greatly increased fatigue strength is a feature of very thin layers of bearing metals has led to the development of thin-shell bearing practice. These bearings are not extensively employed in marine engineering, but are found in some high-speed main and auxiliary engines. Shafts hardened by surface methods are most commonly used with bearings of this type. White metals and lead bronze layers cast-bonded to steel shells are both favoured, although the latter find greatest usage, with or without lead and indium coatings. The excellent anti-friction properties of lead and indium reduce engine frictional losses, and extended use of these metals in bearing applications is expected.

Top-end bearings are made of white metal, lead-bronze or, more commonly, phosphor-bronze bushes, depending on the type of engine, pin hardness, lubrication, and temperature. Bearing metals of similar type are used in pumps, in addition to other bronzes, whilst for underwater service an alloy of zinc 30, tin 68, and copper 2% is frequently preferred.

Stern-tube and rudder bearings are salt-water lubricated, being of lignum vitae and gun-metal mating materials. The stern-tube bearing, supporting the tailshaft and propeller, is of vital importance, as the ship must be docked for examination or repair to be carried out. Wear of the lignum vitae must be kept to a minimum, and as gun-metal has provided a suitable contact metal in this respect, alternatives have not been greatly considered.

Gun-metals within the range 88:10:2 to 87:8:5 or leaded gun-metals of the 85:5:5:5 type are generally employed in the static or centrifugal cast forms for these cylindrical liners. Where facilities are inadequate for casting in the entirety, sections may be cast and joined after shrinkage on to the shaft, by fusion jointing methods. On completion of machining, the liner may be tested to 30 lb./sq. in. pressure to insure soundness before shrinking on to the shaft. Contraction stresses in the longitudinal direction are reduced during shrinking by leaving a region of the bore at the liner centre with clearance and preferentially cooling this section first, after sliding on the shaft. Such regions are pumped up with red lead or similar compound, and the necessary holes, drilled for this purpose, are plugged.

Penetration of sea water between liner and steel shaft may promote corrosion-fatigue failure of the shaft and certainly electrolytic corrosion will occur.

Electrical Features of Metals

Copper is still preferred to aluminium alloys for marine purposes, as are lead alloys for cable sheathing. The influence of alloy additions has been determined in relation to the reduction in conductivity of pure copper. Silver additions of up to 1% result in only small reductions, but offer enhanced resistance to copper shortening.

High resistance alloys are for preference solid solutions, and Constantan (copper 55, nickel 45%) and Manganin (copper 88, nickel 12%) are widely employed; in addition, nickel-chromium alloys are used for high-temperature operation, with or without aluminium, at compositions within the solid-solution range.

Non-ferrous metals offer a wide range of magnetic characteristics which find extensive usage. Nickel forms an important alloying element with iron as a soft magnetic material, the high permeability peaks, at compositions of the order of 50 and 80% nickel, being the most suitable. Permanent magnet alloys contain a number of non-ferrous metals, principally cobalt, nickel,

aluminium, copper, and tungsten. These alloys contain iron as a major constituent, but there are a number of entirely non-ferrous alloys which exhibit useful ferromagnetic properties, although of only limited industrial importance.

Radiography

The non-ferrous metals in radioactive form have many applications in marine engineering. In the radiography of castings and weldments, Indium 192, as applied to steel thicknesses of $\frac{1}{2}$ –2 in. has resulted in high-quality radiographs comparable with those obtained by X-ray methods, particularly at the higher thicknesses. The main disadvantage of this isotope is its short half-life period of some 70 days. Cobalt 60, having a half-life of 5.3 years and used on thicknesses of steel up to 6 in., is widely employed for castings and weldments of thicker section. Light alloys are more frequently radiographed by Thulium 170. Thickness gauging using Thallium 204, Strontium 90 and Iridium 192, in addition to applying back-scattering methods for the measurement of coating thicknesses, or gauging plates and tubes for internal surface corrosion and wastage, illustrate a few of the numerous applications.

Fusion Jointing and Metal Deposition

Soft soldering with tin-lead alloys, with or without antimony and silver additions, is applied where temperature and stress conditions are of a low order. Brazing or hard soldering, involving deposits of copper-zinc alloys or copper-zinc-silver alloys (silver solder), provides joints of superior strength capable of service at high temperatures. The detrimental effects of a tensile stress initiating cracking in steels during hard soldering cannot be overlooked, and the possibility of physical and structural changes in the parent metal, due to the higher jointing temperature should be borne in mind.

The application of these methods to copper steam-pipe flange attachment, providing many years of efficient service, and the jointing of steel shells to copper alloy tube plates in heat exchanger practice, demonstrate their reliability. Bronze welding with filler rods having fusion points exceeding 920°C. imposes limits on the parent metals, of which copper, copper-silicon alloys, cast iron, and steels are the most suitable. Although providing good joints, bronze welding is not widely employed, as methods involving fusion of the parent metal are frequently preferred.

In marine engineering the efficient welding of thick sections is essential and many processes perfected for thin-gauge material have very restricted application. The degree of perfection attained in jointing steels by electric arc welding processes has not been approached by any method applied to non-ferrous metals. In all instances, the degree of success obtained in fusion welding is greatly dependent on suitable preparation, fluxing, the development of efficient techniques, the operator's skill, and pre- and post-heating requirements. Inert gas arc welding processes offer marked advantages when applied to many non-ferrous metals, and the self-adjusting electrodes and argon atmosphere used in these processes have stimulated increased interest in this technique.

Despite the advances in welding processes, the practice of poured welding or "burning on," first established in the foundry, is still used. Repairs to castings of copper alloys, aluminium alloys, and ferrous

materials are most commonly encountered, and with careful procedure and suitable fluxing satisfactory repairs with metal of similar analysis to the base casting, can be achieved.

Deposits of metals and alloys may be applied by fusion methods for reclamation and repair of worn and damaged surfaces or for corrosion-resisting purposes. Depending on the thickness required, either one of the methods referred to may be used or, alternatively, metal spraying may be adopted. Since fusion of the parent metal is rarely achieved and the strength of the deposit is doubtful, reclaimed parts should possess scantlings sufficient to withstand the applied loads before rectification. The building up of bearing surfaces and worn shaft surfaces has been extensively undertaken by this process with good results.

Surface spraying of zinc or aluminium for corrosion-resisting purposes has been applied to steel, zinc being applied to the hulls of small ships and tank surfaces. The tendency for coatings to be porous requires that deposited metals should be anodic to the base metal, and fusion welding is preferable where severe erosion conditions prevail.

Electrodeposition of non-ferrous metals for reclamation, corrosion protection, and decorative purposes has become so well established as to require little comment. Nickel and chromium deposits have proved reliable for the reclamation of worn surfaces and in some cases have been preferred: of the two metals, nickel has been most favoured. Cadmium plating of steel in contact with aluminium has been proposed, the favourable electrode potential of cadmium being utilised on the surfaces of steel bolts and similar items in contact with aluminium.

Non-ferrous metals are readily used in all these deposition processes, but fusion-welding methods have not yet attained the efficiency required for marine purposes, particularly in regard to aluminium alloys, some alloys with aluminium contents, and many high-temperature materials. The use of these materials is being influenced by this feature and can be increased only by the introduction and development of more efficient and reliable welding methods.

Fabrication Features

A high proportion of non-ferrous metals is used in the cast condition for marine engineering purposes, copper alloys being the principal materials concerned. A large number of these castings having weights less than 10 cwt. are used for valve bodies and components, pump parts, bushes, brasses, and similar items, whilst stern tube parts, tailshaft liners, larger pump casings, impellers, and turbine-nozzle castings more commonly weigh between $\frac{1}{2}$ and 5 tons. Propeller castings are frequently of 30-40 tons weight in the cast condition, of which some 25-35% may be removed in machining operations. These items comprise some of the largest castings made in non-ferrous alloys and demonstrate the castability of the alloys and the high degree of foundry control employed.

Propeller castings of high tensile ($\alpha + \beta$) brasses or manganese bronzes are still extensively used, although aluminium bronzes are increasing in popularity as a result of their superior erosion qualities and increased strength, which permit greater flexibility in design. Although modified β -brasses of the high-tensile type offer excellent strength qualities, the liability of these alloys to intercrystalline cracking in sea water forms an undesir-

able feature. However, a limited number of propellers has been cast in alloys of this structure containing 2% nickel and having tensile strengths of 35 tons/sq. in. Nickel additions of this order to normal manganese bronzes increase the erosion resistance, but tend to increase difficulties of repair and rectification. Turbadium bronze, an alloy of this type, has been employed fairly extensively, the propellers of the *Queen Mary* of some 32 tons finished weight being typical examples. Failures due to defective castings are comparatively infrequent, indicating the generally high quality obtained.

The improvement in pressure-tightness of bronze castings effected by lead additions has resulted in a preference for this form of alloy. Low pressure valve bodies and parts, sea connections, liners, and similar parts have, therefore, been cast in both these materials. Manganese, nickel and aluminium bronzes have been extensively employed for high-pressure parts and more severe temperature conditions, although for steam chests steels are being more extensively used.

Centrifugal-casting methods are extensively employed where the form of the components is adaptable to the process. Both chill and sand moulds are used, the former for gear blanks and bushes, where the improved structures at the chilled surfaces are of importance; sand moulds are employed for tailshaft liners and stainless-steel piston crowns.

The higher-strength alloys are taking precedence for cast machinery parts, the aluminium bronzes being the most popular. Difficulties due to the aluminium content do not appear to be unduly severe for casting or welding, provided that reasonable precautions are taken. Vulcan hydraulic coupling rotor and clutch parts have been cast in these alloys, the intricate oil passages being readily reproduced and the strength being adequate for rotational speeds in excess of 750 r.p.m.

Aluminium alloy castings are most commonly used for lower-strength parts where ease of handling is essential. Sand and die cast pistons of these alloys are widely used for the smaller oil engines, as in other industries. Die casting and precision investment casting of non-ferrous alloys have not been extensively used in marine engineering, although high machining costs have led to consideration of these methods for low-stressed turbine and other machinery parts, at present machined from wrought materials.

Wrought alloys are used for shafting purposes in extruded, rolled, and, less frequently, forged form. The convenience of rolled or extruded round bar is useful for shafting having loose steel couplings. In consequence, as a result of the generally available sections and economic considerations, shaft diameters in excess of 5 in. are rarely used.

Aluminium alloys used in ship construction are not made in such convenient sizes and sections as steels, and a tendency to increase the sizes of plates, in particular, has been in progress to meet these demands. Cold working of plates and sections to obtain more favourable mechanical properties imposes limitations on welding, in that the weld and fusion zone will be inferior in strength to the remaining parent metal.

The use of the plasticity of non-ferrous metals is of value for jointing purposes. Metal gaskets are most commonly of lead, aluminium, tin, nickel, Monel metal, and copper. Selection of the metal depends on the pressure, temperature, type of joint, and possibility of galvanic action with the flange material.

Recent Research in the American Iron and Steel Industry*

Investigation of Fundamental Metallurgical Problems

IN the last 50 years of the 19th century the annual output of the American iron and steel industry rose from barely 500,000 tons (with only 6,000 tons of steel) to 11,000,000 tons; during the same period, the production of a single blast furnace rose from 150 tons a week to some 400 tons a day. Such progress could only have been achieved by a concentrated study of the techniques of iron and steel making, although industrial research as it is known to-day did not come into existence until 1900.

In that year several pioneer industrialists discovered that by financing research they could obtain the information which they needed for improving their manufacturing processes and products. The considerable technological problems involved were tackled by breaking them down so that a team of workers could study them simultaneously.

Prior to 1900 American steelworks had concentrated on the development of more and more powerful handling equipment for ingots, blooms, sheets, etc., of ever greater size. During this same period much valuable metallurgical research was carried out in Europe, thereby creating the research tools necessary for the development of industrial research in America.

To-day numerous fundamental researches on metals are undertaken in the laboratories of universities and research institutes, often aided by industry and by the American Iron and Steel Institute and other technical societies. The laboratories of metallurgical companies are mainly occupied with the solution of problems of applied research and with technical improvements, although there are exceptions.

Several examples of researches on fundamental metallurgical problems will be discussed in the following pages.

Diffusion

The discovery, by Kirkendall and others, of the dual nature of the phenomenon of diffusion has led to renewed interest in the subject in recent years. It was shown that at an interface between two metals, *A* and *B*, the diffusion rates of *A* into *B* and of *B* into *A* are different. Before this effect was verified by Mehl and da Silva for combinations of some copper alloys and of gold and silver, Darken had evolved a mathematical treatment for this problem, involving two diffusion coefficients. It is important to base calculations not on concentration gradients but on activity gradients, when the flux of material diffusing is proportional to the free energy gradient.

Radioactive tracer techniques can greatly speed up studies of diffusion by simplifying the difficult task of analysis. The mechanism of diffusion in interstitial

solid solutions, such as those of carbon and nitrogen in α -iron, is generally agreed to be one of insertion, and a representation of this phenomenon on the basis of statistical mechanics would seem to be possible: Zener and Wert have attempted this. For substitutional solid solutions the diffusion mechanism is less certain. Confirmations of the Kirkendall effect render the hypothesis of vacant lattice sites more probable since the concept of rotating blocks of atoms is inadequate to explain this.

Grain Boundary Structure

Since 1921 it has been supposed that in solid solutions, (of whatever concentration) the atomic arrangement at the grain boundaries is less disorientated than would result from a simple orientation gradient from one grain to another. The hypothesis put forward to account for this, involving the concept of the diffusion of vacant lattice sites, is now well established, mainly due to the relationship observed between interfacial energy and the difference in orientation of adjacent grains.

In North America the most recent studies in this field are those of Aust and Chalmers at Toronto University, and of Dunn and his colleagues at the Pittsfield works of the General Electric Company. In Great Britain Greenough and King have published a noteworthy study on the free interfacial energy.

It is only when differences in orientation are too great and require too high a density of dislocations that the theory falls down, as pointed out by Shockly and Read in 1949.

A knowledge of the absolute values of interfacial energies may permit a definitive representation of grain boundary structure to be made. The electron microscope, together with studies of diffusion at grain boundaries and of the internal friction during deformation, should throw further light on the architecture of grain boundaries in metals.

Structural Hardening

Recently, in America, several theories have been advanced capable of explaining the observed structural hardening phenomena as studied by such workers as Guinier and Preston. Possibly the major American work has been that of Barret and Geisler, who have developed an improved technique for detecting and identifying coherent precipitates—the first stage of hardening. Softening is attributed to a diminished cohesive force in the lattice, to a growth of precipitation with the formation of particles lacking cohesion between them, and also to the recrystallisation of the impoverished solution surrounding areas of precipitation. Geisler deserves mention for recognising the heterogeneity of the reaction, since initially precipitation must occur at positions of high energy (notably on slip planes and at grain boundaries) and subsequently only in regions where the energy is close to the maximum value.

* An abridged translation of a paper by E. C. Bain, published in the August, 1953, issue of *Révue de Métallurgie*.

Internal Friction in Solid Solutions

Work has been pursued on the subject of internal friction in solid solutions, to verify the hypotheses of Zener, Snoek, Wert and others on the role of interstitial atoms and their ability to migrate as a result of changes of stress. A suitably applied stress causes the atoms of carbon and nitrogen in a single crystal of iron to migrate to larger lattice sites, from which they are again displaced as the stress changes. By employing a suitable frequency, the damping of naturally oscillating stresses has been found to be proportional to the amount of carbon or nitrogen in solution. This method could be adapted for determining the solubility of a substance in interstitial solid solution at different temperatures.

Deformation Structure, Recrystallisation and Grain Growth

In recent years the process of recrystallisation has been studied by Mehl, Anderson and others. The parameters of nucleation (N) and growth (G) have both been found to increase with temperature and deformation. G remains constant during deformation at a given temperature, while N increases up to a recrystallisation of 30–40%.

Harker and Parker have shown how grain growth develops in such a way as to minimise the curvature of grain boundaries until all the dihedral angles of boundary intersections approach 120° . Burke and Becke and others suggest that the origin of grain growth lies in the tendency for a grain to reduce its surface (or more correctly its free energy) to a minimum. Following the work of Guinier, Crussard and others in France, Fullam and Dunn, in America, have made a study of polygonisation. At present a clear picture of the precise state of atoms at grain boundaries is lacking, and hypotheses involving dislocations and vacant lattice sites are only reliable when the angular differences in orientation are small.

Atomic Arrangement

Chang and Reed have studied a martensite type of transformation in a gold-cadmium alloy having a face-centred cubic structure. When a single crystal of this alloy is cooled to about 60°C ., it transforms without diffusion into an aggregate of orthorhombic grains. On reheating, the original structure is regained. A peculiarity of this aggregate is its low modulus of elasticity, which is of the order of 8.6×10^5 lb./sq. in. The shear effect produced by the applied stress appears to be opposed to that due to the transformation, so that deformation by slip on certain planes is impossible. Barret and his co-workers at the Institute of Metals, Chicago, are seeking an explanation of the martensitic type transformations in lithium and lithium-magnesium alloys.

Several widely differing techniques are being used in America at present for investigating the arrangement of atoms in a number of intermetallic compounds.

Plastic Deformation and Rupture

A new impetus has been given in America to research on plastic deformation and rupture by the somewhat belated adoption there of Ludwigs theory and the concept of two parameters (critical shear strength and rate of hardening) deduced from the curve of plastic deformation. Low and Gensamer showed conclusively in 1943 that the yield point and ageing are associated

with the presence of carbon and nitrogen. Gensamer measured the relative efficiency (at equal weights) of various addition elements in increasing the critical shear strength of steels. The elements studied, arranged in order of decreasing importance, were phosphorus, silicon, titanium, manganese, aluminium, molybdenum, nickel, vanadium, tungsten, cobalt and chromium. This order is approximately that of increasing total solubility and of the progressive decrease in the difference in atomic radii. Gensamer also showed that, as the critical shear strength of steels increased, the parameter of work hardening decreased.

Recently Jackson, Smith and Lankford have conducted extensive researches on the plastic deformation of metal sheets possessing the characteristic anisotropy of cold rolled strip. They applied a tensile stress in directions making various angles with that of rolling. The interpretation of the results only involves a consideration of the two parameters previously mentioned and the relation between deformations when the stress is (a) parallel to, and (b) perpendicular to the direction of rolling. From this information, and from a knowledge of the deformation curve for the sample under tension in one of these directions, a general relation between tension and deformation may be deduced.

In the same field, Bridgman at Harvard University is continuing researches on the application of the theory of deformation and flow. He has found the elongation to rupture to be proportional to the rate of hydrostatic compression under which his samples were deformed in monoaxial tension. The elongation under very high pressures may be very much greater (up to 300 times) than that in simple tension, and when this is so the sample will also exhibit a considerable elongation to rupture in the ultimate tensile test. The explanation given for this phenomenon is that under large hydrostatic pressures dislocations and vacant lattice sites become "neutralised" and, consequently, unable to initiate rupture. Bridgman has also been able to develop extremely large forces in certain parts of his testpieces.

The occurrence of brittle fractures in a number of large welded structures has stimulated research on the behaviour of notched bars and, in particular, on the temperature of transition from ductile to brittle fracture. Stout and McGeady and Gensamer and Vanderbeck have drawn a distinction between the transition temperature given by the appearance of the fracture and that corresponding to the sudden decrease in the energy absorbed from a swinging pendulum. The latter is by far the more important. Parkes and Davis have shown that in samples fractured below the transition temperature the surface of fracture exhibits the (100) planes, while after plastic failure such a surface consists mainly of facets at an angle of 45° to the (100) plane of cleavage. This suggests that plastic failure may be due to final shearing.

Harris and Rinebolt have concluded from a systematic study of pearlitic steels containing addition elements that nickel and manganese lower the temperature of transition while carbon, copper, molybdenum, phosphorus and silicon cause notch fragility to appear at higher temperatures.

Decomposition of Austenite

In America studies on the transformation isotherm have become more or less routine practice, and some

explanations of the reaction kinetics have already been put forward. Since 1940, Mehl and some of his co-workers have demonstrated the applicability of a formula involving only the rate of nucleation (which unfortunately is not always exactly constant) and the velocity of radial growth of the nuclei. By means of this the quantity of pearlite formed at a given temperature can be calculated. They conclude that the pearlite nuclei originate on cementite because, unlike the proeutectoid ferrite, the plates of ferrite in the pearlite bear no simple orientational relation to the original austenite. This accounts for the preferential growth of pearlite in a direction parallel to these plates. The low rate of nucleation in comparison to that of growth at temperatures just below the A_3 point is explained by the large number of nodules in a single colony involving several "pearlite" grains.

It has been found that the structure of a steel—for example, grain size, inclusions, etc.—has little or no effect on the growth of nuclei but greatly influences the rate of nucleation. Because of the high rate of nucleation at temperatures where the transformation is quickest, it is easy to see why furnace operation, which governs the tendency towards grain growth and the nature of inclusions, has such a marked effect on hardenability.

There is general agreement (apart from Hollomon and his school) on the essential characteristics of martensite as they emerge from the excellent studies of Cohn, Averback and others and of Troiano and Greninger. Martensite is considered to be a highly supersaturated interstitial solid solution of carbon in α -iron, with the carbon atoms preferentially distributed to yield a tetragonal structure whose dimensions are proportional to the carbon content. Martensite is formed by nucleation and by rapid shearing in an aggregate of lenticules unable to transform individually. Successive nucleations consist of repeated shearings which result in new needles of martensite appearing as the temperature falls. These needles form instantaneously without any type of diffusion. During tempering the first phenomenon to occur is the migration of carbon from the martensite to form a carbon-rich transition phase—probably Fe_3C . Prolonged heating results in the formation of cementite within this intermediate phase. In the first stage of tempering, martensite loses its tetragonal structure and contracts. There is an even greater contraction during the second stage, but this is masked by the simultaneous transformation of retained austenite, which is accompanied by a volume increase.

Another interesting phenomenon is observed when the austenite, either before or during its transformation, is held at a temperature close to the M_s point. This treatment reduces the quantity of martensite produced on cooling to the M_f point, due to a relaxation of the energy associated with the dislocations which constitute martensite nuclei.

The orientational relationships between austenite and its transformation products at different temperatures have recently been studied in several ways, and Tables I and II summarize the results obtained.

An excellent overall picture of American research on such subjects as the rupture of metals, work hardening, metallic interfaces, and the techniques of metallurgical research may be derived from the reports of annual seminars held under the auspices of the American Society of Metals before the regular meetings.

TABLE I.—CRYSTALLOGRAPHIC RELATIONS IN THE DECOMPOSITION OF AUSTENITE TO PROEUTECTOID FERRITE AND FERRITE IN PEARLITE AND BAINITE.

| Phase at Low Temperatures | Planes Parallel | | Directions Parallel | | Common Plane |
|---|-----------------|--------------------------|---------------------|--------------------------|------------------|
| | Austenite | Phase at Low Temperature | Austenite | Phase at Low Temperature | |
| Proeutectoid Ferrite... (Mehl, Barret and D. W. Smith). | (111) | (110) | (110) | (111) | (111) (Belaiew) |
| Ferrite in Pearlite .. (G. V. Smith and Mehl). | (110) or (321) | (112) or (331) | (331) | (321) | High indices |
| Ferrite in Bainite Transformed at:— | | | | | |
| 450° C. | (111) | (110) | (211) | (110) | (111) |
| 350° C. | (111) | (110) | (211) | (110) | Continual change |
| 250° C. (G. V. Smith and Mehl) | (111) | (110) | (110) | (111) | High indices |

Process Metallurgy

Turning to research on the fundamental techniques of industrial extraction metallurgy, there is a sustained interest in slag/metal equilibria. The deoxidation constants for various substances are now known with precision, and the effects of temperature on all steels which react in contact with them are being actively studied. The work of John Chipman and his co-workers at the Massachusetts Institute of Technology is well known. The ternary diagrams for various oxide systems have been more thoroughly worked out, and sulphur distribution between molten steel and different slags, which is important for a knowledge of equilibria and also of the kinetics of reaction as equilibrium is approached, has been studied. There is also renewed interest in the study of the effect of temperature.

Refractories and the changes they undergo during use have been studied in both reflected and transmitted light (using thin sections). In practice comparative softening tests at successively higher temperatures are adequate for estimating the behaviour of normal or high silica bricks. Fireclay bricks, fired at high temperatures, are of interest for possible use in mixer furnaces, replacing basic bricks. These bricks would also be excellent for blast furnace linings but for the disadvantage of cracking, which has yet to be overcome. A comparison of American and European experience in the use of unfired basic bricks in mixer and open-hearth furnaces would be of value.

TABLE II.—CRYSTALLOGRAPHIC RELATIONS IN THE MARTENSITE TRANSFORMATIONS

| Specimens | Planes Parallel | | Directions Parallel | | Junction Plane |
|---|-----------------|------------|---------------------|------------|----------------|
| | Austenite | Martensite | Austenite | Martensite | |
| Steel containing 0.55 to 1.4% C ... (Smith and Mehl, Kurdjumow and Sachs, Wasserman.) | (111) | (110) | (110) | (111) | (225) |
| Steel containing more than 1.4% C and Fe-Ni Alloys ... (Greninger and Troiano.) | (111) | (110) | (110) | (111) | (259) |
| Iron Alloy with 22% Ni and 0.8% C .. (Greninger and Troiano.) | (111) within 1° | (110) | (110) within 2° | [111] | (259) |
| Iron Alloy with 30% Ni ... (Nishiyama and Wasserman.) | (111) | (110) | (211) | (110) | |

Little work appears to be in progress at present on the nature of inclusions in steel. Methods of separating these inclusions have been progressively improved and are equally applicable for the extraction of carbides in order to elucidate their structure.

It is in the field of applied research and of improvements to manufacturing processes that the American steel industry normally exerts its main effort. This is understandable in view of the great current (1952) demand for steel which requires maximum production with existing means and, in particular, an increase in the production of iron to overcome the relative shortage of scrap.

Higher blast pressures have yielded encouraging production results. It has been possible to blow at rates up to 96,500 cu. ft. of air per minute, thereby making about 1,620 tons of iron per day, but attention is now directed towards the use of more moderate blowing rates. The use of oxygen in the blast furnace does not appear to be of value for the production of ordinary iron, but has great advantages in ferro-manganese production.

Many blast-furnace engineers are of the opinion that improvements in the control of the size and refractoriness of the burden are worth while in view of the resulting increase in production. In particular, the reduction in the volume of flue dust largely offsets the costs of crushing and screening and the agglomeration of fines. Laboratory work on such subjects is limited, and even pilot plant trials are only partially conclusive. Full scale works trials can alone provide the answers to such questions. Several new varieties of coal have been washed, blended and then coked in experimental furnaces to determine the best means of utilising inferior grades.

There is a trend towards the use of large capacity

electric furnaces of more than 20 ft. in diameter, melting 100 tons or more of steel with a considerable economy in power consumption. In areas where ore and coke are scarce, all such techniques using scrap are competitive but there are also several furnaces using a large proportion of molten iron in the charge. The system of roof charging, where employed, permits a saving in time. In open-hearth practice trials are being continued on all basic furnaces. Suspended basic roofs have already given good results and enable much higher roof temperatures to be employed.

Trials continue on the use of a gas/oxygen flame to maintain the ingot head liquid in order to reduce piping without having recourse to the normal feeder head. This technique is not yet commercially employed to any extent.

It has been observed that additions of rare earth elements improve the hot plasticity and rolling qualities of certain high alloy steels, and cerium and lanthanum have been used for the same purpose in misch metal.

The cold rolling of tinplate strip presents numerous problems which must be overcome before the full advantages of the system can be realised. In this field, apparatus for testing and control is of primary importance, and many steel research laboratories have a special electronics section.

With the eventual exhaustion of the Mesabi ore deposit studies continue on the concentration of taconites. At the same time the ash and sulphur contents of coals are continually increasing, and even washing can only partially check this trend. In spite of these difficulties there has been no lowering of steel quality.

Co-operation between research and the American iron and steel industry will certainly continue in the future.

Nickel Concentrator Capacity Increase

ENLARGEMENT of the capacity of the concentrator at the Creighton Mine of The International Nickel Company of Canada, Ltd., to 12,000 tons of ore a day, represents a 20% increase in output. The length of the mill building, which is 175 ft. wide and 70 ft. high, has been increased to 465 ft. and the addition of two crushers and 36 flotation machines brings the respective totals up to 4 and 180.

The capacity of the mill, in which nickel-copper ore is separated from rock before smelting, has been enlarged twice in response to increased nickel demand for defence and civilian requirement. When it was designed in 1948, it was to have a daily capacity of 6,000 tons, but plans were changed in 1950—two weeks after the outbreak of hostilities in Korea—to enable the mill to accommodate 10,000 tons of ore per day. The new capacity of 12,000 tons is, therefore, double that which was originally planned.

The concentrator is at the site of Creighton No. 7 shaft, completed in 1951 at one of International Nickel's oldest operating mines—Creighton, which has a record of production dating back to 1900. The shaft brought to 14 the number in operation at the Company's mines. The Creighton concentrator is a compact, steamlined plant with unusual features of design and operation. The head-frame and hoist house are integral parts of the mill building, and ore from the mine is hoisted directly into the crushing plant. Part of the mill feed is carried by conveyor from another Creighton shaft two-thirds of a mile away. The grinding mills are among the largest

in the world. The plant's water supply is obtained through a 6-mile pipeline, and the bulk concentrate—a thin, mud-like mixture—which comes from the mill is pumped through another pipeline to Inco's reduction plants at Copper Cliff $7\frac{1}{2}$ miles away.

New B.I.F. Company

BRITISH INDUSTRIES FAIR, LTD., has now been set up to take over the organisation and management of the British Industries Fair to be held in 1955, and subsequently. The Birmingham, Section of the Fair will continue to be organised and run by the Birmingham Chamber of Commerce as hitherto, but the Company will be responsible for publicity at home and overseas for the Fair as a whole. SIR ARTHUR J. G. SMOUT, J.P., has been appointed Chairman, and the other Directors are:—MR. W. J. ARRIS, M.C., Managing Director of the Burroughs Adding Machine Co., Ltd.; MR. C. K. HORNE, Sales Director, Triplex Safety Glass Co., Ltd.; MR. H. N. HUME, C.B.E., M.C., Chairman Charterhouse Industrial Development Co., Ltd.; MR. F. R. B. WHITEHOUSE, M.B.E., Chairman and Joint Managing Director of the Chad Valley Co., Ltd.; and SIR ERNEST GOODALE, M.C., Chairman and Managing Director of Warner & Sons, Ltd.; and MR. R. P. S. BACHE, Managing Director of Geo. Salter & Co., Ltd. (appointed by the Presidents of the Board of Trade and of the Birmingham Chamber of Commerce respectively). MR. J. L. READING, at present Director of the London Section of the Fair, has been appointed General Manager of the Company. This will ensure continuity of management, the need for which was so strongly stressed in the Goodale Report.

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Institute of Metals

Joint Meeting with French Society

FOR the first time in its history, the Institute of Metals acted as host to a foreign metallurgical society when it held its Spring Meeting jointly with the Société Française de Métallurgie from Monday, April 26th to Saturday, May 1st, with an extension to Tuesday, May 4th for members and ladies of the French Society. Members of the Iron and Steel Institute were invited to attend on the same basis as members of the Institute of Metals, and as the Société Française covers both ferrous and non-ferrous metallurgy, a technical session on ferrous metallurgy was arranged in co-operation with the Iron and Steel Institute. The Annual General Meeting and the scientific and technical discussions were held at Church House, Westminster, in halls in which the House of Lords and House of Commons met during the war.

The Annual General Meeting on Tuesday, April 27th was followed by a cocktail party at which members of the British Societies were able to meet and chat with their French colleagues, and on Wednesday evening a banquet and dance was held at Grosvenor House. Members and ladies of the Société Française de Métallurgie were received by The Right Hon. Duncan Sandys, M.P., on behalf of Her Majesty's Government on Tuesday evening, and a further official reception was held on Thursday at the French Embassy.

The Meeting opened officially at the Royal Institution on the evening of Monday, April 26th, when the President and members of the Société Française de Métallurgie were welcomed by the President, Professor F. C. Thompson, on behalf of the Institute of Metals, and by Professor Sir Cyril Hinshelwood, F.R.S., Foreign Secretary of the Royal Society, on behalf of British Science. Following the opening ceremony, the forty-fourth May Lecture was delivered by Professor L. F. Bates, F.R.S., Lancashire-Spencer Professor of Physics and Deputy Vice-Chancellor of the University of Nottingham, on the subject of "The Domain Structure of Ferromagnetic Metals."

Business Meeting

The official business of the Annual General Meeting of the Institute of Metals was dealt with on Tuesday morning, when the Report of Council for the Year Ended, December 31st, 1953, and the Report of the Honorary Treasurer and Accounts for the Financial Year Ended June 30th, 1953, were adopted.

Officers for 1954-55—The Secretary then announced the names of members elected to fill vacancies in the Council for the year 1953-54, as follows:—

President : DR. S. F. DOREY, C.B.E., F.R.S. (Chief Engineer Surveyor, Lloyd's Register of Shipping, London).

Vice-Presidents : DR. MAURICE COOK, (Joint Managing Director, Imperial Chemical Industries, Ltd., Metals Division); DR. L. B. PFEIL, O.B.E., F.R.S. (Director, The Mond Nickel Co., Ltd.); and MAJOR P. LITHERLAND TEED (Assistant Chief of Aeronautical Research and Development, Vickers-Armstrongs, Ltd.).

Ordinary Members of Council : MR. R. D. HAMER (Vice-President and Director, Aluminium Laboratories, Ltd., Banbury, and Director, Magnesium Company of Canada, Ltd.); and MR. G. P. TINKER (Managing Director, Birlec, Ltd., and Director, Birmingham Electric Furnaces, Ltd.).

As previously announced, DR. MAURICE COOK is to be Senior Vice-President for the year 1954-55, and he will be the Council's next nomination for the Presidency of the Institute.

Presentation of Presidential Badge—The Institute now has a Presidential Badge of Office, thanks to the generosity of the Directors of Johnson, Matthey & Co., Ltd., on whose behalf the badge was officially handed over by Mr. Donald McDonald (Joint Managing Director). Professor Thompson, having been invested with the Presidential Badge, expressed the Institute's appreciation of the gift before introducing the new President, Dr. S. F. Dorey.

Award of Medals and Prizes—The Secretary announced that the Council had made awards of medals and prizes as follows:—

The Institute of Metals (Platinum) Medal for 1954 to DR. LESLIE AITCHISON, Honorary Member, in recognition of his services to metallurgy in industry, in education, and in public services.

The Rosenhain Medal for 1954 to PROFESSOR ALAN HOWARD COTTRELL, Member, in recognition of his outstanding contributions to knowledge in the field of physical metallurgy, with special reference to the deformation of metals.

Student's Essay Prize for 1953 to MR. DEREK HULL, Student Member, of the Department of Metallurgy, University College, Cardiff, for an essay on "The Characteristics of the Martensite Transformation."

The Presentation of medals and prizes was made by Dr. Dorey following his Presidential Address, which is reported elsewhere in this issue.

Technical Sessions

Technical sessions for the presentation and discussion of papers were held on Tuesday afternoon, Wednesday morning and afternoon, and Thursday morning. Three concurrent technical sessions were held on Wednesday and two on Thursday, one of the Wednesday programmes taking the form of an all day symposium on "The Control of Quality in the Production of Wrought Non-Ferrous Metals and Alloys." Part II—"The Control of Quality in Working Operations." The papers presented at the various sessions are listed below, the date following the title indicating the date of publication in the *Journal of the Institute of Metals*, except where otherwise stated.

Tuesday

- (1) SULLY, HARDY and HEAL, "An Investigation of Thickening and Metal Entrapment in a Light Alloy Melting Flux" (October, 1953).
- (2) Jointly: CHADWICK, MUIR and GRAINGER, "The Effect of Iron, Manganese and Chromium on the Properties in Sheet Form of Aluminium Alloys Containing 0.7% Magnesium and 1.0% Silicon" (October, 1953), and HARRIS and VARLEY, "Factors Influencing Brittleness in Aluminium-Magnesium-Silicon Alloys" (April, 1954).

Wednesday—Programme A (Symposium)

FORD and WISTREICH, "Problems of the Control of Dimension, Shape and Finish in the Rolling of Sheet and Strip and in the Drawing of Wire" (March, 1954); KING and TURNER, "The Control of Quality in the Hot and Cold Rolling of Aluminium and Aluminium Alloys" (March 1954); KEE, "The Control of Properties and Structure in the Hot and Cold Rolling of Copper and Copper-Base Alloys" (March, 1954); SMITH and

(Continued on page 248)

Electrode Development and Manufacture

New Quasi-Arc Laboratories at Bilston

FOR over forty years the Quasi-Arc Co., Ltd., has occupied a leading position in the welding electrode and equipment industry, and to-day, with its associated companies, it is the largest manufacturer of such products in the British Commonwealth. During this time the company has been closely associated with such pioneering efforts as the first all-welded ship, the first all-welded bridge and the first all-welded gasholder. To-day, electrodes are required for welding almost the entire range of metals and alloys, and the welds they produce must meet very high standards of quality, and as the severity of the service conditions set by industry increase, so too must these standards be raised.

Because of the need to ensure a high quality product, to provide a first-class customer service, and to carry out research and development work, the company has always recognised that adequate laboratory facilities are essential. In pursuance of this policy a new laboratory block has been built and was opened recently by Mr. J. S. Hutchison, Chairman of the British Oxygen Group of Companies. Approximately 8,500 sq. ft. of floor space is provided by the single storey structure, which is steel framed, faced with red brick, and designed with provision for the addition of a second storey at a later date.

Work of the Department

The new block is concerned particularly with electrodes, whilst research and development on welding equipment is carried out in separate laboratories. In addition to its activities in developing new electrodes and improving existing products, the Research and Development Department is also responsible for the quality control system which plays such an important

part in electrode production at Bilston. Wire, other raw materials and blended powders for electrode coverings are checked for composition and other features before they are released to production; electrodes are examined and samples tested at several points during manufacture to ensure that consistently reliable products, conforming to close specifications, are always supplied to the user. A complete historical record is available of every carton of electrodes packed.

Electrode development is constantly in progress in the search for electrodes to weld new materials or having special welding characteristics, and for new and better covering materials. Research work on problems common to the development of a number of electrodes or on basic problems concerned with weldability is also always in hand, either as individual researches carried out by Quasi-Arc, or in conjunction with other laboratories.

Service to users of welding is an important part of the work of the Research and Development Department in investigating problems encountered and advising on materials and techniques.

Description of the Laboratories

The interior of the building is designed to be clean, streamlined and airy. This is achieved by means of maximum window space, glass brick partitioning, lofty ceilings, extensive use of fluorescent lighting, completely concealed services and the use of modern-style decoration in washable pastel colours. The main distribution of all services is contained in ducts, large enough for maintenance personnel to pass through, beneath the floors and above the ceilings of the corridors. Sub-distribution in the laboratories is by means of

under-floor ducts and covered wall chases. The scale of services is sufficient to cater for all foreseeable future demands, and provision has been made for the introduction of power to any future equipment occupying island sites, without the necessity for trailing cables.

Electrode Development.—The electrode development laboratory contains pilot equipment for the development and production of experimental electrodes. The main floor space is taken up by various types of blenders, mixers and extrusion machines to suit the different types of covering flux and the different stages of the experimental work. There are also several electrode drying ovens, including a high temperature electric furnace with a maximum temperature of 1,000° C. which is also used for the heat treatment of test plates and other relatively large objects.

There are two annexes attached to this laboratory. One is the wire, powder and solution storage room, which also contains grinding and sieving equipment. This arrangement segregates the more dusty operations from the main laboratory.



General view of the electrode development laboratory showing the mixing and extruding equipment.



General view of the chemical analysis laboratory.

The other annexe contains four test welding bays which are used for examining prototype electrodes and preparing test plates for batch testing and official approvals. These welding bays are supplied with up to 1,200 amps. per operator through various types of Quasi-Arc A.C. and D.C. welding equipment. The welding bays have their own control panels with switches, voltmeters, ammeters, and polarity reversal switch, and there is a master control panel which can indicate any one of the bays. This panel faces outwards into the main laboratory. There is a large tinted observation window in the centre, and provision has been made for the use of recording equipment and sub-standard instruments when required.

Chemical Analysis.—The large chemical laboratory, with north lighting, is laid out for the chemical analysis of a wide range of minerals, metals and alloys, and is the mainstay of the quality control system.

The general arrangement consists of four island work benches in the centre of the room, with fume cupboards, titration racks, furnace benches, and general washing up benches ranged round the walls. Particular attention has been paid to the design of the fume cupboards. They are built along a wall facing the ends of the four island benches so that workers on these benches all have direct access. All the fume cupboards, except the one containing the hydrogen sulphide generator, have open fronts with no doors, sufficient draught being provided by a fan situated on the roof to clear both the cupboards and the laboratory. The fume cupboards are all constructed with hardwood and glass and painted on the insides with acid resisting paint.

The titration racks back on to a wall panelled with vitrolite which is lighted by concealed fluorescent strip elements to give an even illumination. The burettes are

replenished by vacuum from aspirators beneath the titration bench. The same vacuum pump provides vacuum service to the four island benches. Leading from the analytical laboratory is a thermostatically controlled balance room containing a number of aperiodic and Sartorius balances. All waste pipes are made of chemical lead and are run in under-floor ducts with detachable covers, the whole arrangement being designed to give easy maintenance.

Spectrographic Analysis.—This important analytical section is equipped with the latest model Hilger large quartz and glass prism spectrograph, together with a Judd-Lewis comparator and a photo-electric microphotometer. This equipment greatly increases the range and speed of analytical work associated with quality control, and therefore extends the coverage over raw materials and current production, at the same time lessening any likelihood of holding up production. The same laboratory houses a Spekker absorptiometer, which also increases the rate at which certain types of routine analyses can be carried out.

Metallography.—The metallography laboratory is equipped for the microscopic examination of metals and alloys with a Vickers Projection microscope, a binocular research microscope and a general purpose metallurgical microscope. This equipment is used mainly for research into the constitution of weld deposits and for assisting investigations into customers' welding problems. In addition, a petrological microscope is provided for the examination of minerals, and is a valuable aid in identifying minerals and their impurities in flux materials. The microscope room is placed adjacent to the spectrographic laboratory, and both rooms communicate directly with a common work room. All the ancillary operations of both laboratories are carried out in this room, namely grinding, polishing, etching and the preparation of



General view of the mechanical testing laboratory showing fatigue impact, tensile, hardness and other testing machines.

samples for the spectrograph. In this way it is possible to maintain the utmost cleanliness in the two adjacent laboratories.

Mechanical Testing.—The principal equipment in the mechanical testing laboratory consists of an Avery 100-ton hydraulic tensile testing machine, separate Izod and Charpy impact testing machines, a Wöhler type rotary fatigue tester, a Dennison short time stress-rupture creep machine, a Vickers diamond hardness tester and a large Magnaflux crack detector. The tensile, Izod impact and hardness testing machines are in regular use as part of the routine quality control system as well as for approval tests and other purposes. The Charpy impact, fatigue and creep testing units are more specialised machines for use in the development of weld metals having special properties, and for other general research.

Physical Testing.—This laboratory is equipped for carrying out a variety of work connected both with the development of new electrodes and with quality control, such as heat treatment of alloys, dilatometry, moisture absorption testing, corrosion testing and measurement of the robustness of electrode coverings. Three special humidity cabinets are provided which can be automatically controlled at selected temperatures and relative humidities. They are used both in electrode development and in routine quality control to measure the resistance of electrodes to absorption of moisture. Electrodes are exposed to the selected conditions for a given period of time, after

which the amount of moisture absorbed and its effects on the welding properties of the electrodes can be determined.

X Ray Diffraction.—This laboratory houses a Newton Victor Raymax X-Ray diffraction unit, having a maximum output of 10 mA at 100 kV. The use of this new equipment greatly assists research into the constitution and structure of alloys, and investigation of minerals and their impurities.

Industrial Radiography.—For the radiological examination of test welds there is a Newton Victor X-ray unit, which is used both in quality control and in the development of new electrodes. The capacity of the unit is 250 kV which is sufficient for the radiography of mild steel sections up to about 3 in. in thickness. The X-ray unit is suspended from the jib of a hoist which enables the tube to be set at any working position in the room. The room itself is of special construction having cavity walls containing a 1½ in. thick rendering of barium sulphate plaster to prevent transmission of radiation. Large lead-lined sliding doors provide wide access for trolleys when required for carrying heavy work. The control panel is situated in an adjacent room and the doors to the laboratory are fitted with interlocking switches so that the unit can be operated only from outside, and with both doors closed.

Dark Rooms.—The special photographic requirements of the metallographic, spectrographic and X-ray sections of the laboratory are met by two adjacent, fully equipped dark rooms.

Institute of Metals Meeting (Continued from page 245)

SWINDELLS, "Some Factors Affecting the Quality of Extrusions" (March, 1954); and WHYTE, "Statistical Control in Metal Working Operations" (March, 1954).

Wednesday—Programme B

- (1) **Theme: Precipitation Hardening.** Jointly: HOPKIN and THWAITES, "The Effect of Minor Additions on the Age-Hardening Properties of High-Purity Lead-Antimony Alloys" (January, 1953); POLMEAR and HARDY, "Some Metallographic Observations on Aged Aluminium-Copper Alloys" (April, 1953); HARDY, "Ageing Curves at 110°C. on Binary and Ternary Aluminium-Copper Alloys" (February, 1954); SILCOCK, HEAL and HARDY, "Structural Ageing Characteristics of Binary Aluminium-Copper Alloys" (February, 1954); and K. M. ENTWISTLE, "Changes of Damping Capacity in Quench-Ageing Aluminium-Rich Alloys" (February, 1954).
- (2) **Theme: Creep.** Jointly: LATIN, "Some Observations on Creep and Fracture from Investigations on Lead Cable Sheath Alloys" (July, 1953); R. C. GIFFINS, "Structural Studies of the Creep of Lead" (September, 1953); J. P. DENNISON, "Some Creep Characteristics of a Group of Precipitation Hardening Alloys Based on the Alpha-Copper-Aluminium Phase" (November, 1953); BETTERIDGE, "The Low-Stress Torsional Creep Properties of Pure Aluminium" (December, 1953); HOPKIN and THWAITES, "The Effects of Some Constitutional Factors on the Creep and Fatigue Properties of Lead and Lead Alloys" (December, 1953); in CHANG and GRANT, "Mechanism of Creep Deformation in High Purity Aluminium at High Temperatures" (February, 1954).

Wednesday—Programme C

- (1) FAST and VERRIJ, "Diffusion of Nitrogen in Iron" (January, 1954*).
- (2) Jointly: COTTERELL, "Assessment of Weldability by Rapid Dilatation Tests" (May, 1953*); STEVEN and MAYER, "Continuous Cooling Transformation Diagrams of Steels" (May, 1953*); and COTTERELL, "Effect of Hydrogen on the Continuous-Cooling Transformation Diagram for Mn-Mo Steel" (March, 1954*).

* Journal of the Iron and Steel Institute.

- (3) CRUSSARD and PHILIBERT, "New Theory of Martensite Transformation."†
- (4) BOULANGER, "Phenomena of Overheating in Aluminium Alloys."†
- (5) NOREAN and BERNARD, "Research on Selective Oxidation of Nickel-Chromium Alloys at High Temperature."†

Thursday—Programme A (Metal Physics Session)

An informal discussion on "Recovery and Recrystallisation," arranged by the Metal Physics Committee was introduced by contributions by Dr. R. W. K. HONEYCOMBE and PROFESSOR P. LACOMBE.

Thursday—Programme B

- (1) **Theme: Continuous Casting.** Jointly: LEWIS, "Techniques for the Investigation of Thermal Conditions in Continuous Castings" (April, 1954); and PUTMAN, "The Use of Autoradiography for Finding the Solidification Boundary in Continuously Cast Aluminium" (April, 1954).
- (2) **Theme: Molybdenum and Molybdenum Alloys and the Arc Melting of Metals.** Jointly: RENDALL, JOHNSTONE and CARRINGTON, "The Forgeability Creep Strength and Ductility of Molybdenum and Some of its Alloys," (April, 1954); HOPKIN, JONES, MOSS and PICKMAN, "The Arc Melting of Metals and its Application to the Casting of Molybdenum" (April, 1954); and MOSS, "The Pressure Welding of Molybdenum" (April, 1954).

Visits

The programme included visits to works, laboratories and places of interest in the London area, during the time of the joint meeting, and members of the Société Française de Métallurgie also had the opportunity of making similar visits in Birmingham, Cambridge, Sheffield or South Wales on Monday and Tuesday, May 3rd and 4th.

† Papers of the Société Française de Métallurgie, presented and discussed in French.

NEWS AND ANNOUNCEMENTS

Iron and Steel Institute A.G.M.

THE Eighty-fifth Annual General Meeting of the Iron and Steel Institute will be held on Wednesday and Thursday, 26th and 27th May, 1954. The morning session on Wednesday, 26th May, will take place in the Lecture Theatre at the Royal Institution, Albemarle Street, London, W.1, the remainder of the meeting being held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1. A Members' Dinner will be held at Grosvenor House, Park Lane, London, W.1, on Wednesday evening, and the Rt. Hon. Harold Macmillan, P.C., M.P., Minister of Housing and Local Government, has accepted an invitation to be the Principal Guest.

The Seventh Hatfield Memorial Lecture on "Development in the Iron and Steel Industry in Great Britain during the last Twenty-five Years," will be given by Dr. T. P. Colclough, C.B.E., D.Sc., M.Met., F.R.I.C., on Wednesday morning, 26th May, at 11.30 a.m.

During the session at the Royal Institution the following Medals and Prizes will be presented:—

Bessemer Gold Medal for 1954 to T. P. COLCLOUGH, C.B.E. (Technical Advisor to the British Iron and Steel Federation), in recognition of his distinguished contribution to the development, in theory and practice, of the manufacture of iron and steel.

Sir Robert Hadfield Medal for 1954 to A. H. LECKIE (Technical Officer to the Iron and Steel Board; until recently with the British Iron and Steel Research Association), in recognition of his valuable contributions to research in steelmaking.

Andrew Carnegie Silver Medal for 1953 to G. R. BISH (Enfield Cables, Ltd.; formerly of University College, Swansea), for his Report (written in conjunction with Professor H. O'Neill, who was not eligible) on "The Deformation of Austenite in Relation to the Hardness Characteristics of Steel." (*J.I.S.I.*, 1953, vol. 173, Apr., pp. 398-405.)

Williams Prizes for 1953 (two of £100 each) to A. H. NORRIS (John Lysaght, Ltd., Scunthorpe) for his paper on "Soaking Pit Practice at the Normanby Park Steelworks of John Lysaght, Ltd." (*J.I.S.I.*, 1953, vol. 175, Dec., pp. 353-359), and to E. R. S. WATKIN (Appleby-Frodingham Steel Company) for his paper on "Railway Traffic of the Appleby-Frodingham Steelworks." (*J.I.S.I.*, 1953, vol. 173, Jan., pp. 1-15).

Ablett Prize for 1953 to F. STARKEY (Buckley and Taylor, Ltd., Oldham), for his paper on "Guides and Strippers for Modern Rod and Bar Mills" (to be published later).

Corrosion Conference in Belgium

THE Corrosion Group of the Society of Chemical Industry is to hold a Joint Conference with the Association Belge pour L'Etude, L'Essai et L'Emploi des Matériaux (A.B.E.M.) in Brussels from 1st to 4th June, 1954. A programme of meetings, for the discussion of papers dealing with fundamental and practical aspects of corrosion, and of visits to corrosion test-sites, factories and laboratories has been arranged, and authorities from France, Holland and Sweden have announced their intention of taking part in the Conference. Papers on

fundamental aspects to be presented at the morning session on June 2nd include "The Dry Oxidation of Iron"—L. de Brouckère and M. Solvel (Université Libre de Bruxelles); "The Formation of Phosphate Coatings on Steel"—M. Pourbaix and A. Abd-el-Wahed (Centre Belge de L'Etude de la Corrosion); "The Mechanism of Anodic Inhibitors of Corrosion"—T. P. Hoar (Cambridge University); and "The Mechanism of the Inhibition by Paints of Corrosion"—J. E. O. Mayne (Cambridge University). The following practical papers will be presented the following morning: "A Study of Some Protective Coatings"—E. Leclerc and M. Goldstein (Centre Belge d'Etude et de Documentation des Eaux); "Laboratory Methods of Testing Protective Paint Coatings"—D. Bermane (A.B.E.M.); "Developments in Protective Metal Coatings"—P. T. Gilbert (British Non-Ferrous Metals Research Association); and "Electrical Measurements in the Study of Immersed Paint Films on Metal"—D. M. Brasher and F. Wormwell (Chemical Research Laboratory).

Welding Productivity

THE British Welding Research Association has appointed Mr. A. G. Thompson, B.Sc., A.M.I.C.E., to make an investigation into welding productivity. Mr. Thompson has been associated with the welding and metal fabricating industries for a number of years and has recently been engaged in investigations into product design and production problems with a group of companies in the heavy engineering industry.

Personal News

MR. R. H. S. TURNER and MR. A. PATERSON have been appointed Works Manager and Assistant Works Manager, respectively, of the Trafford Park Works of Metropolitan-Vickers Electrical Co., Ltd. Mr. J. A. BROOKS has been appointed Superintendent, Motor Department; and Mr. A. J. BUDD, Assistant Superintendent, Leonard Works.

ON medical advice, MR. W. S. GIFFORD has resigned his position as Joint Managing Director of Electric Furnace Co., Ltd. He is remaining on the Board of the Company and also on the Boards of its subsidiaries, Electric Resistance Furnace Co., Ltd., and Electro-Chemical Engineering Co., Ltd. Mr. Gifford joined Mr. D. F. Campbell in 1909 to undertake the exploitation in Great Britain of the Heroult electric arc furnace. In 1922, they formed a private company, Campbell, Gifford & Co., Ltd., which later became a public company, Electric Furnace Co., Ltd., of which Mr. Campbell and Mr. Gifford have been Joint Managing Directors since its formation.

MR. H. S. WINGATE, Vice-President and Director of The International Nickel Company of Canada, Ltd., has succeeded DR. P. D. MERICA as President of the Company, and MR. F. M. A. NOBLET, Assistant Treasurer, has been elected Treasurer of the Company and its United States subsidiary, in succession to MR. W. J. HUTCHINSON. Dr. Merica and Mr. Hutchinson will continue as Directors and Members of the Executive Committee and will act as consultants on important projects. MR. T. G.

MONTAGUE, President of The Borden Co., Ltd., has been elected a Director of the Company. As part of International Nickel's executive re-arrangements, Mr. J. R. GORDON is transferring from Copper Cliff to New York City, and Mr. R. D. PARKER has been appointed to succeed him as General Manager of Canadian Operations.

THE Directors of The British Aluminium Company, Ltd., announce that Mr. G. BOEX will be retiring from his Joint Managing Directorship on the 4th July, when he will reach retiring age. Mr. Boex will remain a Director of the Company, and has agreed to carry out any special work as a consultant which the Board may ask him to undertake from time to time. He will be succeeded by Mr. W. J. THOMAS.

METROPOLITAN-VICKERS ELECTRICAL CO., LTD., announce that Mr. S. McCracken, previously Manager of the Belfast Sub-Office, has been appointed a Director of Metropolitan-Vickers South Africa (Pty.), Ltd., and is now in South Africa. He is succeeded by Mr. F. W. Cox.

WICKMAN, LIMITED, announce the appointment of Mr. G. C. BATEMAN as Direct Factory Representative for Lidkopings Mekaniska Verkstads Aktiebolag, Lidköping, Sweden, and Ulsvunda Verkstads Aktiebolag, Ylbsunda, Stockholm, in the United Kingdom and other countries. He will be located at Wickman's Factored Machine Tool Division, Fletchamstead Highway, Coventry. Mr. B. HEAVEN has been appointed as Wickmans own Sales Specialist for Lidköping Centreless Grinding Machines and U.V.A. Internal Grinding Machines for their exclusive territory of the United Kingdom.

MR. B. THORNTON has resigned his Directorship of The Wellman Smith Owen Engineering Corporation, Ltd., for reasons of ill health.

MR. H. P. HUGHES has been appointed Works Manager of the British Electro Metallurgical Company, a Division of Union Carbide Limited.

MR. H. MOORE, who has been with John Harper & Co., Ltd., for 28 years, has been appointed Foundry Sales Representative in the London Area, under the London Manager, Mr. V. A. LLOYD.

NEWMAN INDUSTRIES, LTD., announce the appointment of Mr. W. D. WILSON to the Board of Directors.

WOODALL-DUCKHAM CONSTRUCTION COMPANY LTD., announce the retirement of Mr. R. RAY who, for 26 years has represented the Company's coke oven interests in the North of England and in Scotland. The Company's Sheffield Office will now be closed, and all matters dealt with there will in future be handled by its Representatives at 22, St. Ann's Square, Manchester, 2, or at 1, Castle Street, Edinburgh, 2.

THE United Steel Companies, Limited, announce that Mr. T. S. KILPATRICK, Director and Commercial Manager of Workington Iron and Steel Company, has been appointed a Director of Distington Engineering Company, Limited. Mr. Kilpatrick will be Commercial Manager of both Companies.

MR. R. H. GUMMER, a Director of International Combustion (Holdings), Ltd., has retired from active executive duties after nearly 30 years' service, but will remain a Director of the Company.

BABCOCK & WILCOX, LIMITED, announce that LIEUT.-COL. P. D. IONIDES, D.S.O., has resigned from the Board after 26 years' service. SIR PERCY MILLS, Bt., K.B.E., and Mr. W. F. C. SCHAAPE, the Company's Chief Engineer, have been appointed to the Board.

POWELL DUFFRYN-COPPEE, LTD., announce that the following have been appointed Directors of the Company: Mr. G. MOSTART, Mr. P. EWEN, Mr. P. LE HODEY, SIR H. WILSON SMITH, K.C.B., K.B.E., Mr. G. W. ALEXANDER and Mr. K. A. HOGAN.

MR. M. RIDDHOUGH, Technical Manager of Deloro Stellite, Ltd., is spending two months in the U.S.A., surveying current hardfacing and cutting tool practice.

BAKER PLATINUM, LTD., announce the resignation of Mr. D. JAMES as Managing Director, and the appointment of Mr. S. R. BRYANT to that position.

MR. J. F. PRINCE, Export Sales, and Mr. A. E. TAYLOR, Home Sales, have been appointed Deputies to Mr. T. G. TRAVIS, Sales Manager, Witton Engineering Works of The General Electric Co., Ltd.

THE English Electric Company, Ltd., announce that Mr. H. M. MATHEWS, C.I.E., M.I.E.E., has been appointed Director of Engineering, responsible for co-ordination and direction of the technical policy of the Company.

THE temporary appointment of Dr. J. PEARSON as Head of B.I.S.R.A.'s Steelmaking Division, in addition to his existing appointment as Head of the Chemistry Department, was announced at the beginning of this year. The dual arrangement is now made permanent and Dr. Pearson is confirmed in his second appointment.

SUNVIC CONTROLS, LTD., announce that following on the resignation of Mr. H. BENTON, they have appointed Mr. F. N. YATES, 36a, Brownsville Road, Heaton Moor, Stockport, Cheshire, as their North Western Representative.

Obituary

We regret to record the deaths of the following:—

MR. THOMAS ALLEN, formerly Managing Director of Gibbons (Dudley), Ltd., and of Gibbons Brothers, Ltd., who died on April 9th at the age of 77. Mr. Allen joined the company at the age of thirteen and was actively engaged for 60 years, during which time he was instrumental in securing the licence for the erection of Kogag coke ovens in this country.

MR. PHILLIP T. WARD, son of Mr. Ashley S. Ward, President of Thos W. Ward, Ltd., and a Director of the company, who died on April 29th, in a Sheffield hospital after a long illness. Mr. Ward, who was 35, was also a Director of Birchley Rolling Mills, Ltd., Darlington Railway Plant and Foundry Co., Ltd., and John Williams (Wilshaw), Ltd.

MR. H. J. CHAYTOR, for a number of years District Engineer at the Liverpool Contracts Office of British Insulated Callender's Construction Co., Ltd., who died recently at the age of 74. Mr. Chaytor was at the time of his retirement in 1940, District Engineer at Manchester.

MR. W. P. SNEDDEN, Chief Technical Engineer of the Rolling Mill Division of British Timken, Ltd., who died on April 23rd.

MR. JAMES ERIC EVA, Deputy Chairman and Secretary of Eva Brothers, Ltd., who died on April 3rd in Capetown South Africa.

MR. L. E. WHITE, District Engineer at the Erith Contracts Office of British Insulated Callender's Construction Co., Ltd., who died recently in his 56th year.

RECENT DEVELOPMENTS

MATERIALS : PROCESSES : EQUIPMENT

Dual Current Rectifier

THE Industrial Products Department of Philips Electrical Ltd., announce the introduction of the new Philips Type 1308/2 Dual Current Rectifier which is designed to give an output of 40-240 amps. A.C. or 10-80 amps. D.C. In both the A.C. and D.C. ranges, the output is infinitely variable, and a calibrated scale is fitted to indicate the welding current on either of the two ranges. The type of current is selected by the use of a changeover switch.

When direct current is required, the transformer output is fed to two rectifier valves, which are protected from premature loading by a time-delay valve, and from excessive current input by a micro-switch device operated directly from the shunt mechanism. The use of valve-rectified D.C. ensures that the welding current is smooth and free from "flickering." Since there is no mechanical inertia and the electrical inertia of the set is low, there is a very rapid response and arc-recovery time is extremely short. Oscillograms show that barely 0.002 seconds are required for recovery. Most other types of D.C. plant require 10 times as long.

The Philips Type 1308/2 welding rectifier is suitable for connection to three phase 380-440 volts, 50 cycle supply but can also be supplied for two phase systems 200-220 volts, 50 cycle as desired. The machine is contained in a well ventilated, stoutly constructed, drip-proof case of pleasing design. The valves are fully spring mounted for arduous service. The approximate overall dimensions of the 1308/2 are 22½ in. × 24 in. × 34 in. high, and the approximate weight is 385 lbs.

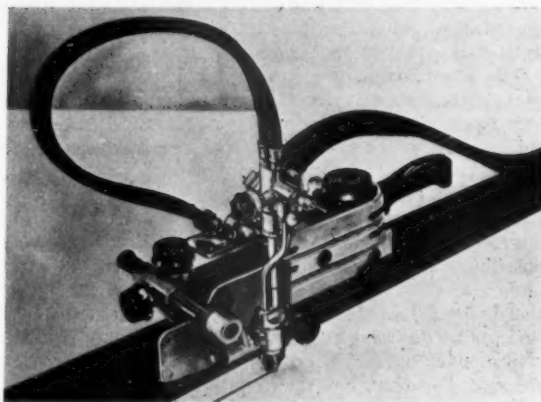
Applications for which the plant is particularly suitable include the welding of light alloys, non-ferrous metals and light gauge sheet. Carbon arc welding can be carried out, and in addition, the generous A.C. range permits the use of the plant for general welding construction and fabrication, repair and maintenance welding.

Philips Electrical, Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

Portable Flame Cutting Machine

THREE years ago Oxhycarbon Co., Ltd. brought out the Quicky portable flame cutting machine, which found a very ready home in shipbuilding, boiler making, structural and general engineering, and repair work all over the country. It was capable of doing most of the work that previously had had to be done by heavier and more expensive machines, and it also became widely used for ordinary straight line cutting in fabricating and repair shops, on work previously done by hand cutters. The result was more accurate work and a better finish.

A new and improved model, known as the Quicky 'B' is now available, which incorporates a more powerful electric motor, an improved gear box with worm wheel drive, and a method for raising and lowering the cutter whilst the machine is cutting. This last feature will be much appreciated by all concerned with straight line and circle cutting by machine. The Quicky 'B' is a straight line and circle cutting machine weighing only 13 lb. It is designed to cut steel from ⅜ in. to 2½ in. thick and is powered by a universal 220-240 or 100-120



volt AC/DC electric motor. A simple rheostat comprises the speed control, which is graduated directly in plate thickness to be cut, thus rendering a tachometer superfluous. The machine will cut bevels and, guided by hand, can be used for very simple profile work.

The Quicky 'B' is normally supplied complete with a circle cutting trammel for cutting circles from 2½ in. to 40 in. diameter, a 3ft. guide rail for straight line cutting, and a cutter with box of nozzles. The cutter will work with acetylene, propane, coal gas or hydrogen, provided the correct nozzles are fitted for the type of fuel gas to be used.

Oxhycarbon Co., Ltd., 6, Hainthorpe Road, West Norwood, London, S.E.27.

Microvolt Multelec

As a result of the favourable reaction to a prototype instrument displayed at the British Instrument Industries Exhibition in July, 1953, George Kent, Ltd., have decided to introduce the Microvolt Multelec as a standard product. The instrument accurately records potentials within a minimum full-scale range of 0-100 microvolts, with a source impedance of up to 50 kilohms, which represents a power sensitivity over one million times greater than that of conventional instruments using a galvanometer. Many applications present themselves for such a hypersensitive instrument in research establishments and industrial plants, especially where high source impedances are encountered. The Microvolt Multelec can be used for control purposes; and where safety precautions demand that, for a break in the measuring circuit external to the instrument, top or bottom scale deflection should result, the amplifier employed can easily be set to give the desired result.

There are two sections of the Microvolt Multelec: a robust electronic amplifier and a standard 0-100-millivolt-range Multelec recorder. The amplifier operates at mains frequencies of between 40 and 60 cycles per second, the appropriate synchronous converter being fitted. The D.C. potential from, for example, a thermocouple is fed into a filter unit and is compared with a reference voltage, derived from the 0-100 millivolt Multelec through a 1,000:1 attenuator. Any difference between

these two potentials is passed to a specially designed vibrating-reed converter, which changes it to an alternating potential. This alternating potential is magnified in a three-stage resistance-capacity coupled amplifier, rectified, and fed to the Multelec galvanometer. The resulting deflection of the galvanometer needle is detected by the well known clamping-bar and scissors mechanism, which adjusts the potentiometer output until it is equal to the source potential.

The elimination of errors which may be induced in parts of the complete circuit, has received much attention. The filter circuit is designed to attenuate alternating components which may arrive with the measured signal, while "pick-up" errors associated with the measuring circuit are reduced to negligible proportions by the 1,000:1 attenuator. Manganin resistors are used in the filter circuit, so that thermal errors are limited as far as possible. To limit these errors still further, the entire filter circuit is enclosed in a draught-proof case which also helps to reduce the effect of stray magnetic fields. The vibrating-reed converter, which is the result of intensive research, is so designed that it introduces errors of less than 0.5 microvolts into the circuit.

The input impedance of the filter and amplifier alone is 28 kilohms; but at balance the instrument offers an almost infinite impedance to the source being measured. The instrument is accurate to within 0.5 microvolts with an e.m.f. source impedance of up to 50 kilohms. The over-all sensitivity of the instrument, which depends on the source impedance, can be adjusted to give optimum results by a gain control included in the amplifier circuit.

George Kent, Ltd., Luton.

Rotation Switches for Mechanical Handling Systems

New weatherproof rotation switches made by The General Electric Co., Ltd., have been designed for use with conveyors and other material handling equipment where a continuous process is concerned and warning of a breakdown or partial stoppage is essential. They are for attachment to the lay shaft of a conveyor, and are produced in two patterns, one to break circuit and the other to make circuit in the event of the shaft either stopping or rotating too slowly. They are covered by British Patent Application 11529/51.

An application for the break-circuit switch is to wire it into a relay circuit controlling the motor of the preceding conveyor, so that it automatically switches out that motor in the event of its own conveyor stopping or running too slowly. In a complete series of conveyors, or other material handling plant, each equipped with this device, a chain reaction back to the beginning of the feed could be initiated, and any pile-up of material prevented.

One suitable use for the type which makes circuit is as the last switch in the series described above. It is then wired into an alarm circuit so that an audible and/or visual warning is given when all the other conveyors have been halted or its own conveyor runs slowly or stops.

Each rotation switch is fitted with two mercury switches of either delayed-break or delayed-make type, rated at 5-amp 230-volts A.C. or 1-amp 230-volts D.C.

They are carried in cradles free to swing independently against light pressure, and are moved by two Tufnol cams diametrically opposed on a cam shaft. It is necessary for the switches to remain stationary in either the break or make position (according to type) for three to five seconds before they make or break the circuit. This may be brought about either by a conveyor stopping or going at a speed below that desired. The cam shaft is made of stainless steel and projects through a felt packing gland in the side of the box, so that it can be driven by a suitable coupling from any convenient shaft or take-off point of the machinery.

Unlike centrifugal switches, which need the use of gears if a low speed shaft is the operating member, rotation switches will operate satisfactorily between 25 and 50 r.p.m., which is the speed range of the average conveyor lay shaft or idler. Wear and tear on the switches at these speeds is reduced to a minimum. The switch case is of aluminium alloy with a hinged lid having provision for padlocking. It is dustproof and weatherproof and is tapped with one $\frac{3}{8}$ in. E.T. hole at the top and one at the bottom (one fitted with a plug), to receive conduit or a cable gland. The external dimensions of the case are $8\frac{3}{4}$ in. high by 7 in. wide by $4\frac{5}{16}$ in. deep. Fixing centres are 7 in. by $5\frac{7}{8}$ in. for $\frac{5}{16}$ in. bolts.

Rotation switches are already installed and in use on plants handling crushed limestone up to 3 in. diameter at rates of 25 tons per hour, ground limestone at rates of 25 tons per hour, nitro-chalk granules at a rate of 21 tons per hour, coke up to 6 in diameter at a rate of 70 tons per hour; ash at a rate of 20 tons per hour; and on a horizontal paddle mixer.

The General Electric Co., Ltd., Magnet House, Kingsway, London, W.C.2.

Flame Safety Device

THE latest FSM series of Elcontrol furnace safeguard equipments gives immediate fuel cut-off on flame failure of oil and gas burning equipment, being equally suitable for either. It thus provides complete safety under running conditions, and it can be arranged to give equally complete safety on lighting up, by preventing the admission of fuel until the lighting means are present and in the correct position.

The new principle made use of in the Elcontrol FSM system is the detection of the fluctuating infra-red radiation which is characteristic of every flame, both luminous and non-luminous. The viewing head embodies an infra-red sensitive cell and lens system which is sighted on to the flame through a small diameter tube on the burner front or furnace wall, or axially along the burner tube as convenient. It is connected to the control unit embodying the electronic circuit and operating relays, and which responds only to the modulated signals from the viewing head. Complete discrimination between the flame and hot refractory is thus provided without recourse to sensitivity control. When the viewing head "sees" the flame, the control relay is energised, thus opening the magnetic valve or starting the burner motor. Absence of flame at once causes the relay to be de-energised, giving immediate shut-down with operation of the appropriate alarm signal.

Elcontrol, Ltd., 10, Wyndham Place, London, W.1.

CURRENT LITERATURE

Book Notices

HANDBOOK OF INDUSTRIAL ELECTROPLATING

By E. A. Ollard and E. B. Smith. 364 pp., 122 illustrations and 72 tables. London, 1954. Iliffe and Sons, Ltd., for *Metal Industry*. 30s. (by post 31s. 2d.).

THE first edition of this book, published in 1947, quickly became recognised as a practical and reliable reference book on all aspects of modern electrodeposition plant and plating technique. The steady demand has prompted the authors to undertake a still more comprehensive work, and this greatly enlarged second edition, carefully revised and brought completely up to date, is the result.

It should be emphasised that the book is in no sense a text book: all theory has been omitted and the book describes merely the practical part of installing, maintaining and operating electroplating plant. The second edition contains new sections dealing with water and drainage, the purification of solutions, safety precautions and ventilation in plating shops, and the special problems of costing in such shops. Many new formulae for solutions as well as details of the latest advances in testing deposits are given, while a number of additional tables for reference have been provided. Other subjects dealt with include electrical equipment, deposition plant, solution formulae, special formulae, testing plating solutions and testing deposits. No data has been included on mechanical or electrolytic polishing, in spite of the fact that the first edition was criticised in some quarters on this score, as the authors point out that the subject is dealt with very fully in a companion volume.

The handbook is intended for all those concerned with the design, erection, maintenance or operation of electrodeposition plants, and also for laboratory workers who have to deal with the testing and maintenance of plating solutions. The authors have drawn largely on current literature, but it is their hope that by collecting such data in one volume, the task of all such workers may be greatly simplified.

THE DETERMINATION OF TORSION CONSTANTS FOR BULBS AND FILLETS BY MEANS OF AN ELECTRICAL POTENTIAL ANALYSER

Research Report No. 22. Aluminium Development Association, 33, Grosvenor Street, London, W.1. 7s. 6d.

THIS report describes an electrical potential analyser and its application in determining the torsion constants of bulbs and fillets such as may be used in structural sections. The work is part of the investigations sponsored by the Aluminium Development Association and conducted by Professor S. C. Redshaw at the University of Birmingham.

It has been obvious for some time that the designing of sections which involve the determination of their torsion constants would be greatly simplified if accurate values for a range of bulbs and fillets, as covered herein, were available. This could have been accomplished by using relaxation or soap bubble methods, but the use of an electrical potential analyser has proved to be much quicker. This electrical apparatus is indeed analogous to the mathematical relaxation process, and the results

obtained by the two methods are in extremely good agreement.

The Report, after a brief introduction, and an outline of the mathematics of the torsion problem, describes the apparatus and its operation and then gives test results, in the form of curves and tables, for a number of sections including angle fillets, T-junction fillets, single and double sided bulbs, and sections and fillets with unequal web thicknesses. There are notes on the accuracy of the potential analyser and, for one of the test sections, there is detailed comparison between relaxation and electrical solutions.

Trade Publications

IN a new brochure issued by Darwins, Ltd., covering both corrosion and heat resisting alloys, recognition is made of their common basis of composition and physical properties. Details are given of the range of austenitic and martensite stainless steels made by the company and an indication given of their resistance to corrosion in various environments. For more severely corrosive conditions, Darwins' special corrosion resisting alloys containing large proportions of nickel, molybdenum, chromium, etc., are available as castings of high density and mechanical strength. Following a brief summary of the known effects of the individual elements introduced into modern heat resisting alloys, the properties of a range of alloys of this type, made by Darwins under the trade mark *Pireks*, are set out, concluding with a discussion of their use for carburising boxes, and cyanide and salt bath pots.

THE British Aluminium Co., Ltd., have issued in booklet form, a paper recently read before the West of Scotland Branch of the Institute of Welding on "Some Recent Developments in the Welding of Aluminium Alloys and their Future Applications in the Shipbuilding Industry." Following a discussion of the various processes available for welding aluminium alloys an account is given of the building of the welded aluminium alloy hull of the auxiliary T.S.M.Y. *Morag Mhor*, the largest hull to be so constructed outside America. Finally, the application of welding to large deckhouses, barges, lifeboats and hatch covers is discussed.

A USEFUL little booklet issued by High Duty Alloys, Ltd., Slough, gives the foreign equivalents of the Hiduminium cast and wrought aluminium alloys. The nominal composition and appropriate British specifications are listed followed by official specifications or trade names of equivalent alloys in the U.S.A., Switzerland, France, Germany, Canada and Italy.

JOHNSON, MATTHEY & Co., LTD. have issued in booklet form a paper presented to the Institute of Metal Finishing by E. H. Laister and R. R. Benham, A.R.I.C. Available as Publication 1855 "Rhodium Plating and Its Modern Applications," it deals with the operation of rhodium plating solutions and gives details of working conditions and maintenance. The effects of varying basis metals and undercoats, and of a number of common impurities, are described, together with the results of experiments

designed to demonstrate the resistance of rhodium deposits to corrosive conditions and to heat. The chemical, physical and electrical properties of the deposit are discussed, and the development of the numerous applications of the process shown, many examples being given. Suggestions are made regarding suitable standards of plating for differing conditions.

"WIGGIN NICKEL ALLOYS" No. 24, contains an illustrated description of a unique large scale experiment in lining a reservoir with rubber. This should interest water supply authorities in particular and civil engineers in general. Other articles deal with Monel ragbolts, pipelines of uniform wall thickness, pickling chains, a machine for degreasing skins, marine chronometers and electrical instruments, whilst the high speed cutting of the Nimonic alloys and the production of oxy-insulated Brightray resistance wire are also described. Copies may be obtained from Messrs. Henry Wiggin & Co., Ltd., Thames House, Millbank, London, S.W.1.

CRUCIBLE melting has long been the mainstay of the non-ferrous foundry industry, and The Morgan Crucible Co., Ltd., of Battersea has had considerable experience in making both crucibles and furnaces. The range of Morgan furnaces includes tilting furnaces of the central axis balanced type; direct-pour lip axis models; the versatile lift-out furnace; bale-out furnaces for the die caster; and the rotary crucible furnace for swarf reclamation. Sizes range from 30-1,700 lb. brass capacity and 10-1,000 lb. aluminium capacity, and there is a choice of oil, gas or coke firing. A recently issued leaflet gives brief particulars of the types available.

WE have received from Uddeholm, Ltd., Somerset House, Temple Street, Birmingham, 2, a copy of a booklet on the heat treatment of steel. Following a short explanation of the meaning of TTT-diagrams or S-curves, the various heat treatment processes are dealt with in detail in the light of isothermal transformation diagrams. In a number of instances, reference is made, by way of illustration, to results obtained on certain Uddeholm tool steels.

TUBEWRIGHTS, LTD., a subsidiary company of Stewarts and Lloyds, has recently issued a booklet showing some examples of tubular equipment for use in materials handling. Steel tubes have particular advantages in materials handling equipment as they are light, rigid and strong, and possess high torsional resistance. Moreover, their smooth surfaces render them easy to handle and reduce accidents. This type of equipment has been supplied to a variety of industries and Tube-wrights have also evolved a convertible Pallage system by which a wide range of materials handling equipment can be built up from standard components. Copies may be obtained from the Company at Eggington House, 25, Buckingham Gate, London, S.W.1.

HIGH DUTY ALLOYS, LTD., have the sole licence agreement with Société Anonyme pour l'Industrie de l'Aluminium for the manufacture of S.A.P. (Sintered Aluminium Product) in the British Commonwealth under their patents, and this remarkable new material is now available. The properties at room temperature are equivalent to medium strength aluminium alloys, coupled with resistance to corrosive attack comparable with 99.5% pure aluminium. At elevated temperatures its mechanical properties greatly exceed those of aluminium alloys, and its complete stability and recovery of full properties after prolonged soaking and return to

normal temperature are unique in the field of aluminium-base materials. A new booklet has been issued dealing with this material, which has been designated Hiduminium 100.

MODERN methods requiring rapid assembly of components demand a versatile range of silver brazing alloys. A new publication of Baker Platinum, Ltd., lists the physical properties of the Silvaloy series of brazing alloys designed to meet this need. They are the product of many years research by Baker's American associate company and range from Silvaloy 50 (B.S.1845, Type 3), with a melting range of 625-640°C., to Silvaloy 850, a silver-manganese alloy (for joining Nimonic and other high temperature alloys) for which the corresponding figures are 960-976°C.

THE Quasi-Arc Co., Ltd., of Bilston, Staffordshire, have just issued a six-page illustrated Technical Circular, No. T.C.898, describing their D.C. arc welding rectifier Type MR.375, the first metal rectifier welding plant introduced into this country and now installed in a number of leading shipyards and engineering works, having a welding current range of 25-375 amps. The MR.375 provides D.C. power for welding at a higher efficiency and instantaneous arc response. The technical circular sets out in detail the numerous advantages to be gained by using the MR.375 welding rectifier, including characteristic volt/ampere curves and a table showing typical test results in power consumption as compared with motor generators. A complete specification of the MR.375 is also given, as well as a description of the portable current-selector unit which provides complete remote control.

WE have received from L. Light & Co., Ltd., Poyle Estate, Colnbrook, Bucks, a copy of their 1954 catalogue of organic research chemicals. This new list covers a wide range of amino acids, peptides, biochemicals, nucleotides, sugars, enzymes, steroids, pterins, alkaloids, bile acids, vitamins, flavones, synthetic drugs, amines, chromatographic and analytical reagents, carcinogenic hydrocarbons, hydrides, solvents, nitriles, silanes, fluorines, monomers, acetylenes, hydrocarbons, photographic intermediates, quinoline and pyridine derivatives.

Books Received

"Metallurgy of Welding." By Walter H. Bruckner, B.A., B.Sc., Ch.E. 290 pp. inc. numerous illustrations. London, 1954. Sir Isaac Pitman & Sons, Ltd. 30s. net.

"Procedures in Experimental Metallurgy." By A. U. Seybolt, Ph.D., and J. E. Burke, Ph.D. 340 pp. inc. index. New York and London, 1954. John Wiley & Sons, Inc., and Chapman & Hall, Ltd. 56s. net.

"Microscopical Techniques in Metallurgy." By Henry Thompson, A.I.Prod.E., A.R., Ae.S., A.M.I.E.I. 146 pp. inc. numerous illustrations. London, 1954. Sir Isaac Pitman & Sons, Ltd. 18s. net.

"Materials and Processes." By James F. Young. Second Edition. 1,074 pp. inc. numerous illustrations and index. New York and London, 1954. John Wiley & Sons, Inc., and Chapman & Hall, Ltd. 68s. net.

"S.S. Ocean Vulcan Sea Trials." Detailed Analysis of Record No. 6.E.7 (Loaded Condition). The Admiralty Ship Welding Committee Report No. R.10. By authority of the Lords Commissioners of the Admiralty. 187 diagrams. London, 1953. Her Majesty's Stationery Office. 42s. net.

METALLURGICAL DIGEST

Controlling Carbide Precipitation in Welding Stainless Steel

By G. E. Linnert, and R. M. Larrimore, Jr.

FABRICATORS of austenitic grades of stainless steel are aware of the damage by intergranular corrosion resulting from carbide precipitation near welded joints, and the authors summarise the practical methods of controlling the carbide precipitation. Although there is a temptation to take a short cut or to use a makeshift measure to effect control in a welded component, there are only three dependable methods suitable for positive control:

- (1) Post-weld solution annealing treatment.
- (2) Stabilisation of the carbon with strong carbide-forming elements like niobium, tantalum, or titanium.
- (3) Use of a stainless steel having an extra-low carbon content.

Each method has certain limitations; thus selection will depend on many factors, such as size of the weldment and availability of suitable equipment for heat treating and descaling; the current supply of material in regular, stabilised, or extra-low-carbon grades in the size and quantity needed; and the service conditions under which the weldment will operate.

Post-Weld Heat Treatment

Heat treatment after welding is the oldest means of avoiding intergranular corrosion in the sensitised zones of welded austenitic stainless steels. The usual treatment consists of a solution anneal which involves heating the weldment to a temperature high enough to dissolve any intergranular carbides and to restore vital chromium to depleted boundary areas.

This operation is carried out in the temperature range of 1,000–1,120° C. The optimum temperature depends on the grade, while soaking time is determined by the section. Short time at temperature is preferred to avoid grain growth, and a rough rule is to soak the material at temperature three minutes for every one-tenth inch of thickness to ensure solution of the carbides. The weldment must be

cooled rapidly, at least through the temperature range of approximately 900 down to 430° C., to retain the carbon in solid solution. Water quenching or water spraying is necessary for heavy sections and air cooling is permissible only for very light sections.

Disadvantages of this treatment are the high temperatures required, distortion that occurs in heating, and the problems associated with the quenching operation. When an oxidising atmosphere is employed during heating and cooling, the surfaces must be descaled by pickling, sandblasting, or some other suitable process.

The chance of stress-corrosion cracking is another reason for post-heat treatment. As with many other commonly used metals, austenitic stainless steels are susceptible to stress-corrosion cracking in certain media, and it is difficult to predict when an environment will produce this defect and to decide how much reduction must be made in the magnitude of residual stress to avoid its occurrence. It has been customary practice with welded austenitic grades of regular carbon content to post-anneal at 1,000 to 1,120° C. to remove the residual stress, since treatment at a lower temperature might seriously impair the corrosion resistance, but rapid cooling from a high temperature can create new stresses of considerable magnitude in the annealed weldment and stress-corrosion cracking can be caused by stresses arising from this source.

Stabilised Grades

The elements niobium, tantalum, and titanium have a stronger affinity for carbon than chromium; therefore, if these elements are present in austenitic stainless steels, they will be precipitated in preference to chromium carbides in the austenitic matrix.

A stabilised grade is required when a component will operate at a temperature within the sensitising range of 430–820° C. and will also be exposed to corrosive conditions. The greater strength of these steels at elevated temperatures is sometimes an advantage. If the component is welded, the

weld deposit may be stabilised with niobium or titanium. One of the gas-shielded arc processes is necessary with the latter element.

Use of stabilised stainless steels in weldments is not entirely free from difficulty with respect to sensitisation. Corrosive attack in very narrow base metal zones immediately adjacent to the weld may give cause for concern. This condition has been termed "knife-line" attack, and results from a characteristic of the stabilised grades not generally recognised. In a very narrow zone on each side of the weld, the base metal is heated to a temperature high enough largely to dissolve the niobium, tantalum, or titanium carbides. If these zones are subsequently reheated to the neighbourhood of 650° C., at which temperature the solubilities of niobium, tantalum, titanium and chromium carbides are very low, chromium carbides will preferentially precipitate in the grain boundaries, because of the greater amount of this element in the alloy. The zones thereby become sensitised and are susceptible to intergranular attack. However, if the zones after welding are reheated to a higher temperature in the vicinity of 870° C., niobium, tantalum, and titanium carbides will precipitate in preference to chromium carbides, because their solubility is lower than that of the chromium carbides.

Extra-Low-Carbon Grades

The use of extra-low-carbon austenitic stainless steels is a newer means of avoiding harmful carbide precipitation in welding and in stress-relief heat treatment. In these materials, a maximum carbon content of 0.03% insures enough immunity to precipitation in the 430–870° C. temperature range to withstand any normal welding or stress-relieving operations without danger of impairing the materials' corrosion resistance. Because carbides will precipitate in appreciable quantities in these 0.03% maximum carbon materials, when held for an extended period of time in the 430–870° C. temperature range, their use is recommended at service temperatures below 430° C.

These extra-low-carbon grades may be stress relieved at temperatures below the customary annealing range without jeopardising the corrosion resistance of the material.

From *Materials and Methods*, Nov., 1953, 98–103.

How to Descale Titanium

By A. E. Durkin

A MAJOR difficulty in the use of titanium alloys is the removal of oxides formed during heat treating and forging operations. When these oxides are not removed, the corrosion resistance of the metal is decreased. It cannot be readily welded and its ductility is materially reduced. Many oxide formations can, however, be removed if the proper descaling process and cycle is used.

Scale Formation

When titanium metal is heated in air, a tight oxide film forms on its surface. This scale consists largely of titanium dioxide, but it also contains some of the lower oxides in the areas adjacent to the titanium surface. The solubility of these oxides in both

mineral acids and molten alkali salts varies with the temperature of formation. Any titanium dioxide formed below 1,300° F. is theoretically soluble in concentrated sulphuric acid. As the temperature of formation approaches 1,830° F. the solubility in mineral acids and molten salts decreases rapidly. A dioxide formed above 1,830° F. is theoretically insoluble. Laboratory tests indicate, however, that any scale formed above about 1,400° F. is practically insoluble in most of the common acid and alkali descaling solutions.

Among the molten caustic type baths investigated for descaling properties were sodium hydroxide, sodium nitrite, the Virgo salt process, and the Kolene No. 4 process. The acid baths

investigated were fluoboric, hydrofluoric, nitric-hydrofluoric, hydrochloric-hydrofluoric, and sulphuric acids. Characteristics, advantages and limitations of the various solutions and processes are summarised in the accompanying table.

Embrittlement

Embrittlement caused by a descaling bath was particularly evident with the molten sodium hydroxide bath. The loss in ductility of commercially pure titanium treated in the temperature range of 850-1,000° F. can be prohibitive from the standpoint of application and fabrication. At 1,000° F., titanium can be thoroughly descaled in 1 min., but its ductility drops from an angle of bend of 180° to one of about 30°. In the Virgo or Kolene bath, no loss of ductility occurred in titanium processed for 30 min. between 800 and 1,000° F.

From *Materials and Methods*, Oct., 1953, 107-109.

DESCALING BATHS EVALUATED

| Bath | Characteristics | Advantages | Limitations |
|---|---|--|---|
| Molten Sodium Hydroxide | Descales titanium at temperatures above 700° F. by dissolving oxides. | Relatively low cost. Availability. | High temperatures necessary for production descaling. At 700° F. the descaling rate is very slow, 40 to 80 min. being required to remove average oxides. Danger of embrittlement above 850° F. Processing temperatures above 700° F. cut descaling time, but ductility is seriously affected. Large stock loss. As processing temperature is raised stock loss increases appreciably. |
| Electrolytic Molten Sodium Nitrite | Descales titanium without embrittlement when metal is made anode at current density of about 2 amp./sq. in. for 3-5 min. | Low operation temperature. No serious stock loss. | Toxic fumes liberated at anode. Shelf life of bath is short. Descaling too slow for production. Large power requirements necessary. |
| Virgo Salt Process | Essentially a caustic soda bath with about 15% oxidizing agents and additives. Marketed by Hooker Electrochemical Co. and widely used for descaling stainless steel. Descales titanium by dissolving oxides (which differs from its action on stainless). | No indication of embrittlement or loss of ductility for bath temperatures up to 1,000° F. Only slight stock loss. | At bath temperatures over 1,000° F., titanium reacts violently with the salts, and fire and explosions may result. This is true of all molten salt baths tested. |
| Kolene No. 4 Process | Caustic type bath. Marketed by Kolene Corp. and used to clean stainless steel and large cast stock. Used both electrolytically and non-electrolytically. | No loss in ductility of metal immersed in either type bath for 30 min. at 800 to 1,000° F. Electrolytic bath offers speed and lower processing temperatures. | At bath temperatures over 1,000° F., titanium reacts violently with the salts, and fire and explosions may result. |
| Fluoboric Acid | Descales titanium in about 10 min. in concentrations of 5% to "concentrated" at 170-200° F. Acid penetrates surface of scale and reacts with metal, flaking off the scale. | No evidence of any embrittlement caused by the bath. Low equipment, installation and operating costs. Retches uniformly. | Large stock loss as high as 8 mils. per surface for heavily scaled stock and 4 mils. for lightly scaled stock. |
| Hydrofluoric Acid or Nitric-Hydrofluoric Acid | Both HF, in concentrations ranging from 10% to "concentrated" and 8% nitric-2% hydrofluoric acid at 140° F. descale titanium by rapidly dissolving the metal beneath the scale. | Effective in short immersion times provided the scale has first been broken. Low equipment, installation and operating costs. | Large stock loss. |
| Other Acids | Sulphuric acid removes light scales. Mixture of 2% hydrofluoric-3% hydrochloric acid at room temperature reacts in the same manner as nitric-hydrofluoric. Mixture of hydrochloric and hydrofluoric acids effective in removing some types of scale. | Solutions readily available in processing or plating rooms. Same equipment advantages as other acids above. | Irregular attack unless scale is broken. |

Soldering of Aluminium

By J. D. Dowd

ALUMINIUM and its alloys can be readily soldered once the oxide film on the surface has been removed. This oxide can be removed mechanically by ultrasonic vibration, abrading with steel-wool, wire-brushing or by some similar means while the surface is covered with molten solder, or it can be removed with fluxes. A chloride-free organic flux is recommended for use with low-temperature solders. With high-temperature solders, it is necessary to use chloride fluxes, the residues of which should be completely removed to prevent subsequent corrosion of the aluminium. Solders for aluminium are generally alloys of lead, tin and zinc, although small amounts of other elements have been added to many such solders.

In general, the resistance to corrosion of soldered joints in aluminium has been found to increase as the zinc content of the solder increases. The best solders from a corrosion viewpoint are zinc-base alloys in which zinc is the lowest melting metal. The resistance to corrosion of soldered joints has also been found to depend upon joint design, environment and effectiveness of protection. Sound soldered joints that are adequately protected have been found to give satisfactory service in various environments for many years.

From *Welding Journal*, March, 1954, 33, 113e.-120e.

LABORATORY METHODS

MECHANICAL • CHEMICAL • PHYSICAL • METALLOGRAPHIC

INSTRUMENTS AND MATERIALS

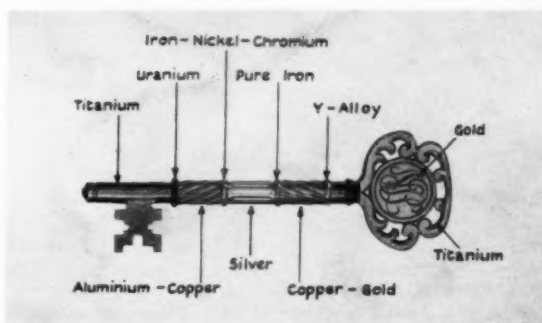
MAY, 1954

Vol. XLIX, No. 295

National Physical Laboratory Extension New Metallurgical Laboratory Opened

A REMARKABLE key was presented to Prof. Sir Lawrence Bragg, O.B.E., F.R.S., when he opened the new laboratory of the Metallurgy Division of the National Physical Laboratory last month. It symbolised over fifty years of scientific work in the development of new alloys, and was decorated with seven different materials, each of which had its story.

One was aluminium bronze, an alloy developed at the National Physical Laboratory during the first decade of the century, and famous for its strength and beautiful golden colour. A second recalled the technical struggle during the First World War, when the performance of an aircraft engine was influenced largely by the quality of its piston, and strong light alloys able to withstand heat were needed. "Y" alloy was then produced, and was the forerunner of a number of special alloys which helped to keep the British aircraft engine in the van of progress until the piston engine itself was surpassed by the jet engine. The early days of heat resisting alloys were represented by an alloy of iron, nickel, and chromium. All modern jet engines contain alloys of these three metals, the possibilities of which were explored over twenty years ago, in a long series of experiments which later formed the basis of Britain's spectacular achievements in this field. In 1941, when the possibility of releasing atomic energy came to be realised, a knowledge



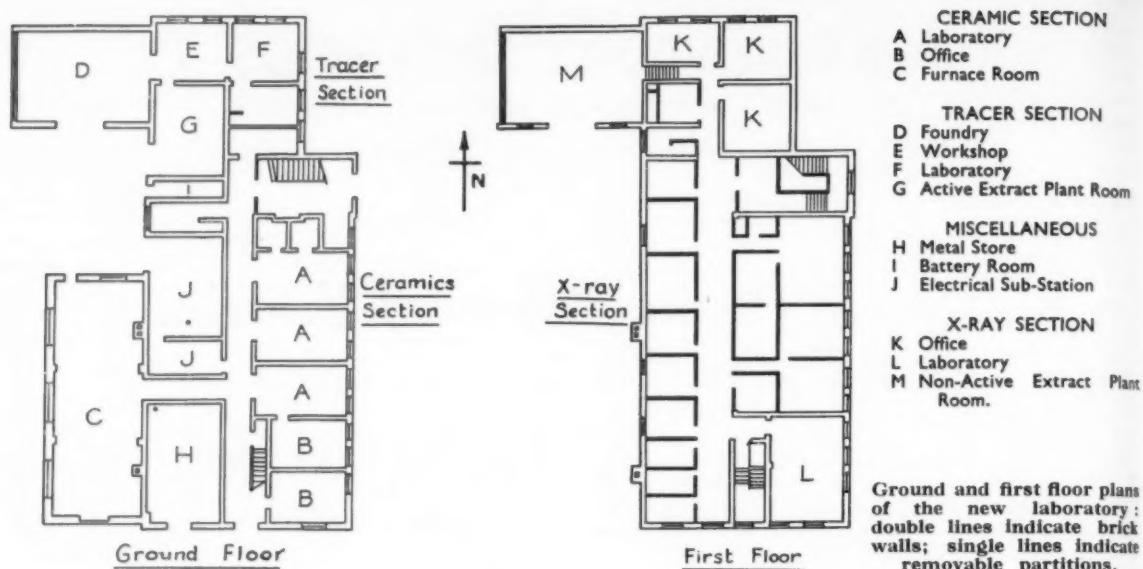
The key used by Sir Lawrence Bragg for opening the building. The metals used in its construction are indicated.

of the properties of uranium was required. They were examined in secret in the ensuing years, and a ring of uranium at the bottom of the key commemorated this work.

Practical improvements must be preceded by fundamental scientific work, and the key contained three metals associated with researches of this kind. One was iron, made to an exceptionally high degree of purity, and used to study the influence of minute traces of



General view of the new laboratory.



impurity, sometimes less than one part in a thousand, which affect the quality of steel. The others were silver and a copper-gold alloy upon which studies of the atomic and electronic structure of metals have been made.

The key itself was made of titanium inlaid with gold. Titanium is a new light metal that has come into use within the last three or four years, and being strong and light, is full of undeveloped possibilities; but gold, the first metal used by man, still holds its own for beauty and permanence.

The Metallurgy Division

In the Annual Report of the National Physical Laboratory for 1901 will be found a reference to the allocation and equipping of two rooms in one of the wings of Bushey House in which the metallurgical research at the Royal Mint, carried out by Sir William Roberts-Austen on behalf of the Alloys Research Committee of the Institution of Mechanical Engineers, was to be continued as part of the work of the newly-formed Physics Department of the Laboratory. One of the rooms was equipped for heat-treatments and metallographic studies while the other was fitted as a laboratory for the chemical analysis of metal samples. Dr. H. C. H. Carpenter, afterwards Sir Harold Carpenter, was appointed to this metallurgical section with one assistant. The work of the section increased rapidly, not only on the research side, but also in the number of metallurgical tests and examinations of failures undertaken, and in the associated field of chemical analysis. The need for expansion was met in 1906 when work was started on a new building, completed in 1907, which is still in service today as the single storey east wing of the present main building.

A very generous donation which had a most important bearing on the whole future of the Department of Metallurgy, was the gift in 1910 of £10,000 by Sir Julius Wernher for the erection of a new building. This took the form of a two-storey block running north and south attached to the western end of the original single storey building, and a new west wing comprising a machine

shop and foundry. On completion in the autumn of 1911, the whole of the original building was given over to the chemistry section. In 1913, a separate building to the north of the Wernher building was erected to house an experimental rolling mill and other equipment for the working of metals, and in 1921, a third storey was added to the Wernher building. Such an addition had been envisaged and provided for when the plans of this building were drawn up in 1910. A separate building to the east of the rolling mill was erected in 1931, and to this the machine shop was transferred, thus enabling the original shop to be re-equipped as a laboratory for high-frequency induction furnaces.

The New Extension

The new extension has been made necessary by the continuous development of techniques for the examination of the fine structure of metals and the growth of interest in the properties of materials at very high temperatures. It consists of a two-storey building on the west side of Bushey Road to the north of the Wernher building, and has a total floor area of about 11,700 sq. ft., of which about 5,800 sq. ft. is experimental working space. Its purpose is to accommodate three sections of the Division—the ceramics section, the X-ray section and a new radioactive tracer section—and each portion of the building has been designed to meet the requirements of the particular type of work that will be undertaken in it.

The ceramics section is on the ground floor and consists of the five laboratories and offices (A and B), approximately 20×11 ft., facing east, to the south of the entrance hall, together with the furnace room (C), 52×20 ft., reached by a short cross corridor. The section is mainly concerned with the development and production of refractory ware for use under exacting conditions, especially those involving very high temperatures. Two laboratories will be used for forming and drying the ware, and the furnace room will permit firing on a considerable scale. This room also contains machines for crushing and grinding, whilst space is left for the

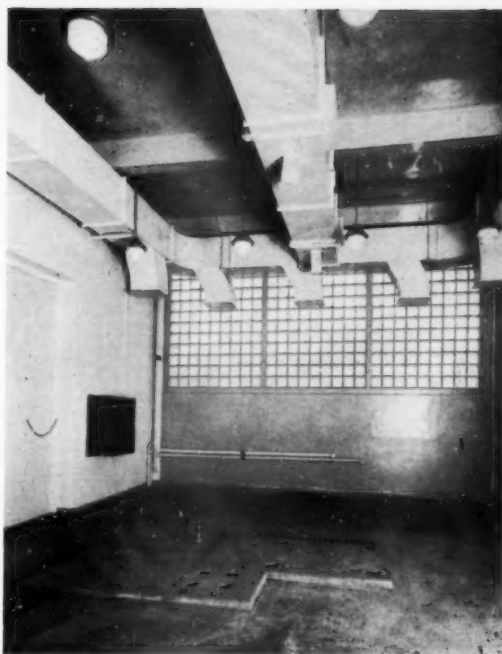
needs of specialised experiments and measurements. The third laboratory is available for physico-chemical research on a smaller scale. Chemical benches, gas, water and electricity have been installed also in the two offices, which can therefore be used, if occasion demands, for work of special delicacy. The development of methods for measuring the technically important physical properties of refractory materials at very high temperatures is expected to be one of the important functions of this section.

The ground floor also provides, to the north of the entrance hall, a set of three rooms for experimental work on the application of radioactive tracer techniques to metallurgical problems. The purpose is to provide a place wherein to apply these techniques, under suitable conditions, to metallic samples, and to assess their value in metallurgical research. Metallurgical laboratories not equipped with these facilities will be invited to submit their problems. The immediate programme includes (1) the development of more sensitive techniques for measuring the activity of very small amounts of active material; (2) the identification and distribution of a particular constituent in a metal as, for example, in investigations involving grain boundary concentration of an impurity; (3) studies of diffusion in metals; and (4) the analysis of activated samples for the determination of extremely small impurity levels in metals.

The plan underlying the design and equipment of the section has been to provide facilities for carrying out, on metals of all but the highest activity, most of the operations normally applied to metals in a research laboratory. The main feature of the section is the foundry (D), a lofty, well-lit room, 30×20 ft., equipped with gas-fired and H.F. induction melting furnaces, casting equipment heat-treatment furnaces, a small bar and sheet rolling mill, and a suitably protected safe for the storage of active isotopes. Provision has been made to handle active metal in quantities up to 6 lb. Next to the foundry is a combined workshop and laboratory (E), 16×13 ft., for metallographic preparations, with a power hacksaw, a lathe, grinding and cutting-off wheels and metallographic equipment (including an automatic polishing machine). Next again is a combined chemical and physical laboratory (F), 15×13 ft., in which chemical analyses and measurements of activity will be carried out. A fourth room (G), also leading from the workshop, contains the active extract plant. The whole section is approached through a semi-sealed door and changing rooms.

Air Conditioning System

The air-conditioning system in this part of the building is completely separate from that in the remainder. Air is drawn into a duct by means of an intake fan in the non-active plant room on the upper floor over the foundry, and, after being warmed to 65°F. , is passed through ducts to each room, from which it is extracted through another system of ducts by a second fan situated in the active plant room on the ground floor. At selected points in the extract duct in each room, openings are provided to which extensions to hoods over machines and other equipment are attached. Before reaching the exhaust fan the air is freed from solid matter. After passing the fan it is released through a high chimney, at the base of which there is an opening for the continuous monitoring of the activity of the filtered air before it is allowed to escape into the atmosphere. The intake and



Part of the radioactive tracer foundry, showing ducting, before the installation of equipment.

exhaust fans are interconnected in such a way as to produce a slightly negative pressure throughout the section; this avoids the possibility of contamination passing to the rest of the building which is kept at a slightly positive pressure by its own system of air circulation. A pre-set differential pressure valve is mounted through the wall above the door leading to the section, with one end in the non-active positive pressure side and the other in the active negative pressure side. If for any reason the pressure in the tracer section should rise above that of the rest of the building, alarm Klaxons would sound. A similar valve connected to the same alarms is placed near the active exhaust fan to cover the possibility of any failure in the inter-relationship between this and the intake fan.

The rooms are designed to be easily washed down, and have floor ducts and sinks down which all active liquid passes through polythene drains to 1,000 gallon delay tanks situated under a small separate pump house. Here it remains until its activity has fallen to a level sufficiently low to permit its transfer to the sewers by means of pumps in the pump house. Separate sinks and drains are provided for non-active liquids (e.g., cooling water from pumps, etc.). Since such liquid might inadvertently be contaminated with active material, it is not discharged direct into the sewers but passes to a separate storage tank, from which it can be pumped after its activity has been checked. Provision is made in the pump house for sampling and monitoring each tank, and bells are installed at suitable points to indicate when a tank is full and another must be brought into operation.

The remaining rooms on the ground floor to the west of the corridor comprise a metal store (H), 26×16 ft., a battery room (I) with a 150 A.H. 110 volt battery, and an electrical sub-station (J) which serves the Division as



Main X-ray laboratory, showing on the left the separate cubicles, each containing one X-ray diffraction set.

a whole. Ducts in a false ceiling to the corridor serve as a main artery for the distribution of all services to both floors of the building. These services include 400-volt 3-phase 50-cycle A.C., 230-volt single phase 50-cycle A.C., 110-volt D.C., a battery supply up to 110 volts in steps of 2 volts, gas, hot and cold water, and compressed air.

The upper floor is designed for X-ray diffraction studies of metals and for electron microscopy. Except for three offices (*K*), and one laboratory (*L*) in the south-east corner, it consists of a single large room, 66 × 44 ft. This room is divided by means of easily removable partitions into a number of cubicles and small laboratories, each of which is intended to contain a single piece of equipment, and each of which can be darkened. By a system of roof lighting it is ensured that no matter how the space is divided, each cubicle can receive full daylight. In this way the need of the individual worker to have sole control of his own equipment is combined with adaptability. The arrangement ensures that a wide range of equipment is available at any time, and preserves sufficient flexibility for new methods to be introduced and older ones discarded, without interruption of active investigations. Equipment not required by immediate programmes may be readily removed from its cubicle and placed in store, and its space employed in building up the equipment for some developing type of work.

As a corollary to the use of removable partitions, all services in the section are carried in a carefully planned system of wall and floor ducts. In addition to the standard services already mentioned, there is a circulating system of clean distilled water, at 50 lb./sq. in. pressure and 20–25° C. temperature for cooling purposes, and a quiet phase of 230-volt A.C. for apparatus requiring short-term mains stability. The input of the ventilating

system for the first floor is shared with the ceramics section below, but whereas from each room in the X-ray section extract ducts lead direct to an exhaust fan on the roof, about 50% of the air extracted from the ceramics sections is recirculated, the remainder being ejected over the roof. As already mentioned this ventilating system is arranged to give a slight positive pressure in both the sections it serves.

The present layout of the X-ray section consists of a row of six cubicles for X-ray sets along the west wall, opening off a common central working space. At one end of these, two dark rooms and a photographic printing room are situated. The X-ray units in four of the cubicles are primarily intended for standard X-ray techniques, e.g., powder camera work and orientation studies, but there is ample space for ancillary equipment to be built when necessary around the apparatus for specialised work. The remaining two cubicles have X-ray sets for Geiger-Muller counter work, and are at present used for high-precision measurements of diffraction line intensities and preferred orientation. In the centre of the building, also opening on to the common working space, is a cubicle containing an X-ray set for work requiring a fine focus source of radiation. Along the east side there is a preparation room for electron microscopy, opening into a central cubicle housing the microscope, and two laboratories for a soft X-ray spectrograph and a recording microphotometer. One cubicle, and the laboratory at the south-east corner are at present unoccupied, and are intended as space for extension and development.

The whole building is heated by hot water through a general system of radiators, except in the radioactive tracer section, where, in order to reduce the number of exposed pipes, etc., to a minimum, floor coils are employed. Additional thermostatically-controlled electric heaters have been provided in some rooms where a drop in temperature overnight or at week-ends would be undesirable.

The building was erected to a design prepared by the Ministry of Works, in consultation with the staff of the Metallurgy Division.

Titanium Shape Casting Licence

OVER a period of several years, National Research Corporation of Cambridge, Mass., U.S.A., has carried on research work directed towards the development of a process for the production of cast shapes of titanium, which involves special melting furnaces, casting procedures, and mould materials capable of withstanding the attack of molten titanium. For almost a year National Research has been experimentally producing small castings of titanium and titanium alloys with good chemical and physical properties. Its experience, know-how, and patents are now made available to industry through non-exclusive licence agreements. With technical assistance from National Research Corporation, the first licensees, Titanium Casting Corporation, division of Howard Foundry Company, Chicago, one of America's principal suppliers of non-ferrous castings for the aircraft industry, will begin the commercialisation of the N.R.C. Titanium Shape Casting Process. By means of this agreement, titanium castings will now be available commercially for use by American industry in applications where their high strength-to-weight ratio or extreme corrosion resistance will be of importance.

Direct Reading Spectrograph for Control of Aluminium Alloy Production

FORMED in 1930, for the production of high quality aluminium ingots for foundry use by remelting metallic material arising in the various stages of manufacture, International Alloys, Ltd., now also produce, from pure metal, alloys which require special care in manufacture, as well as high grade cast billets, also from virgin metal, for rolling, forging and extrusion. In any plant where material is being produced to a specification which lays down composition limits—whether it be in the ferrous or non-ferrous field—the chemical analysis laboratory plays a very important role, not only in checking the composition of the raw materials and the final product, but in keeping the production department on the right lines during manufacture.

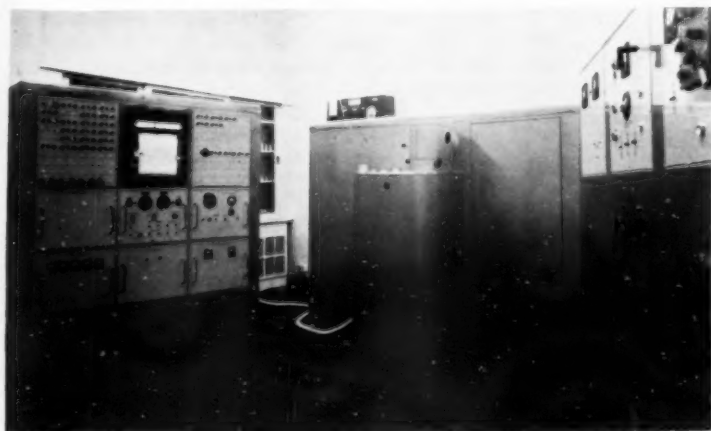
Speed and Accuracy

Two qualities are required of the analytical methods used for these purposes: they must be accurate, and they must be rapid. In the last few years, International Alloys have given much attention to analytical methods, as there was a definite gap between the requirements of the specification and the accuracy afforded by the normal routine methods; the results of this work have been published in a number of scientific journals. Whereas twenty or thirty years ago most analytical work involved the use of volumetric or gravimetric methods for the determination of particular elements or radicals, the modern analyst has at his disposal techniques based on the polarograph, the absorptiometer and the spectrograph. The first two involve preliminary chemical operations and so, in certain cases, does the spectrograph, but metals and alloys can be analysed spectrographically without preliminary weighing, and without taking them into solution. It will be seen, therefore, that the spectrograph offers a means of speeding-up the analytical procedure, but the last few years have seen a remarkable development in this field. Instead of photographing, the

spectrum and comparing it with known standards, the composition of the material is "drawn" on the instrument chart of a direct reading spectrograph. The advantages of almost instantaneous results for samples taken during refining operations will be obvious, and an instrument operating on this principle has been put into operation in the laboratories of International Alloys, Ltd. It is the Production Control Quantometer built by Applied Research Laboratories, Glendale, California. Instruments of this type have been available for more than five years, and have proved their worth in practical use in many light metal works in the United States over a considerable period. Other types of instrument, based on similar principles, are now available, but in view of the fact that the instrument was intended to meet as soon as possible, almost the entire analytical requirements of the production departments, it was decided to choose the design on which the most experience was available.

Mode of Operation

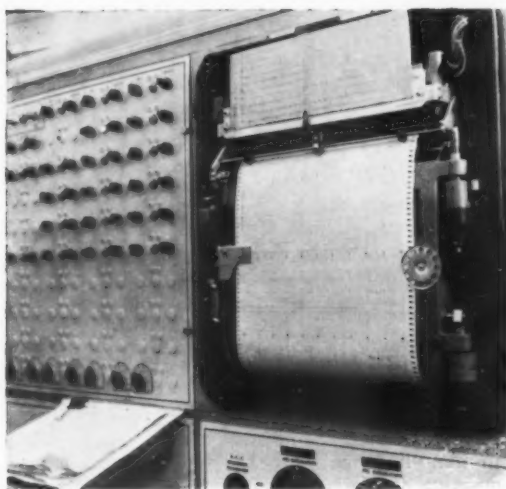
The operations necessary for carrying out analysis for any desired number of components are the following. The sample of metal to be analysed, taken from a specially cast sample slab is about $1\frac{1}{2}$ in. \times 1 in. \times $\frac{3}{8}$ in. in size. One face of this little slab is machined flat to a good finish on a facing lathe, and then placed on the sparking table above a pointed graphite electrode. By pressing a button the operator starts an automatic sequence of operations consisting of the striking of a spark between the graphite electrode and the machined surface of the sample for a period controlled by the instrument itself; the storing of an electrical charge representing the integrated intensity of a suitable spectral line for each of the components to be determined; and, finally, the measuring and recording of these electric charges for each spectral line measured. This whole sequence takes about one minute. After this the



General view of the installation



Inserting the sample

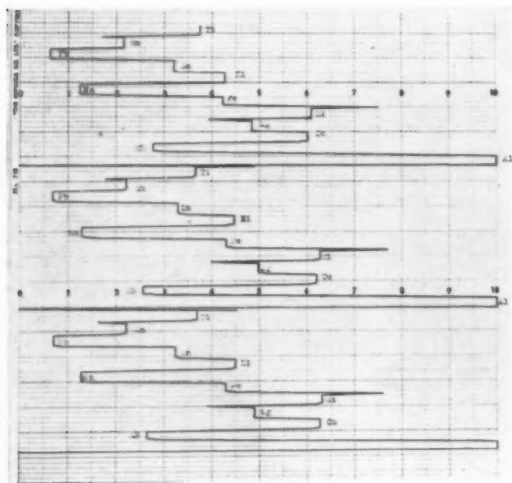


Indicating and recording mechanism. Scale at top is changed with changing alloy types.

operator reads the analysis results from the record or directly from the instrument by means of calibrated scales or graphs.

The instrument has to be "set" for the alloy group corresponding to the sample by a calibration process which is based on standard samples of known composition. Setting of the instrument for the various alloy groups required can be done at the beginning of the shift, and is subject to periodical checks. Between the checks, change from one alloy group to another requires only throwing of certain switches. The total time required from receipt of the sample to issuing the analysis results, in this case for ten constituents, is usually less than five minutes.

A small but skilled chemical laboratory staff is required alongside the Quantometer for providing accurate analyses of the calibration standards and for dealing with non-routine samples.



Three typical results. The full scale deflection at the start of each sample record confirms that the timing has been correct.

Advantages of the Method

The capacity for producing vast numbers of analysis results at a very high speed of operation can best be utilised in dealing with large numbers of samples representing only a small number of nominal compositions.

The benefits which justify the installation of an expensive instrument costing about £15,000 are in the following directions.

- (1) Saving of time in checking raw material and finished products, which means faster turnover in the factory.
- (2) Control of the composition at all stages of the alloying process without appreciable delay. This eliminates surprises in the outcome of melts, a result which could in the past only be obtained at the cost of considerable time loss, owing to the time taken in carrying out even a partial analysis by normal chemical or spectrographic methods.
- (3) Saving in laboratory cost. Under favourable conditions the Quantometer can do the work of 5 to 10 chemists and do it much more quickly. This results not only in a corresponding saving in wages and chemicals, but also in the size and therefore, capital cost of the analytical laboratory.

It is expected that the cost of the Quantometer installation will be recovered by these savings in a period of about three years.

S.G. Iron Producers' Association

The formation is announced of the British S.G. Iron Producers' Association from amongst the licensees in Great Britain and Northern Ireland of the process under British Patent No. 630,070 and others for producing spheroidal graphite iron castings. The Association has been brought into being to facilitate the exchange of information on the manufacture of this new material, and to encourage its use in the large diversity of applications for which it is suitable. It is also co-operating with the British Standards Institution in the preparation of a specification.

MR. P. A. RUSSELL and MR. W. R. COOPER have been elected Chairman and Vice-Chairman respectively, and MR. C. GREY has been appointed Hon. Treasurer. Over 80% of the active producers of S.G. Iron in this country are founder members of the Association. The secretariat and offices are at 94-98, Petty France, London, S.W.1.

The members are taking part in the Exhibition organised by The Mond Nickel Co., Ltd., to be held on May 25th-27th at Park Lane House, London W.1., which, it is hoped, will be attended by a large number of engineers and others who wish to obtain full information on the many uses of S.G. Iron.

Safety Guard Merger

J. P. UDAL and Industrial Guarding Equipment, Ltd., announce that J. P. Udal have recently acquired a substantial interest in I.G.E. This step has been taken to permit both organisations to operate on a broader basis and to secure economies in the export field. The two companies will continue to operate independently on the home market, and to preserve their own individuality in both design and manufacture of their products. There have been no staff changes so that customers can rely on complete continuity of attention to their requirements.

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